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SSM JOURNAL
editorial

Empowering Student Voice at the Heart of Out-of-School Programs and Building Collective Efficacy in Our Schools

Students across the nation begin to lose academic ground in middle school (Barber & Olsen, 2004; Eccles, 2004; Gutman & Midgley, 2000), and the long-term implications of achievement for educational and occupational attainment follow (Eccles & Harold, 1993). Early adolescence and entry into middle school intersects with key changes in developmental processes and structures that include biological and cognitive growth, school context, social development, and family relationships (Adams & Berzonsky, 2008; Grolnick, Price, Beiswenger, & Sauck, 2007; Keating et al., 2004). Meanwhile, as the pressure to connect student outcomes with test scores increases, the broader democratic mission of schools to prepare students to be engaged and contributing citizens (Dewey, 1956) moves further into the rearview mirror. By the time high school commences, students frequently describe their experiences as anonymous and powerless (Earls, 2003; Pope, 2001). During these unsettled times, the need has never been greater to empower the learner, and build resiliency and self-efficacy into the students' learning system. One source of support that may help students, families, and teachers navigate this confluence of developmental and contextual changes to reach their full potential and become actively engaged citizens is quality afterschool programming with student voice at the center.

Beyond the Regular School Day

Unfortunately, research on afterschool program quality is largely descriptive with few rigorously designed studies and evidence of quality program characteristics is often correlational or based on expert opinion (Scott-Little, Hamann, & Jurs, 2002). However, a large-scale, rigorously conducted synthesis looking across many research and evaluation studies across a decade of research and evaluation studies confirms that children and youth who participate in afterschool programs can reap a host of positive benefits in a number of interrelated outcome areas—academic, social/emotional, prevention, and health and wellness (Little, Wimer, & Weiss, 2008). Three messages from Little et al. (2008) research brief were conveyed, describing what it takes to have positive student outcomes: (1) access to and sustained participation in programs, (2) quality programming that has appropriate supervision and structure, well-prepared staff, and intentional programming, and (3) partnerships with families, other community organizations, and schools. The only problem is participation in such programs drastically dwindles during the critical transition from elementary to middle school, though students continue to need caring adult role models and interesting out-of-school activities (Lauver, 2004). Many middle school and high school youth recognize the value of participating in organized activities beyond the school day; yet involvement is often limited because of busy schedules and family lives, disinterest in choices, lack of motivation to attend organized activities over having freedom, and relaxation from daily structured activities.

Access to and Sustained Participation in Afterschool Programs

The National Afterschool and Community Learning Network (Peterson & Spitz, 2003) examined out-of-school time (OST) program sustainability issues in-depth. Across their 16-state analysis, afterschool program coordinators identified sustainability strategies on a 10-point Likert scale, with 1 = "nice" 5–6 = "important," and 9–10 = "critical." They also provided practical advise to those starting programs about how to ensure the program's survival. The following list represents the average ratings from most to least important (Peterson, 2004)

- In-kind resources from school district (e.g., space, supplies): 9.4
- A half-time coordinator paid for by the school district: 8.7
- A meaningful contribution from a local foundation: 7.5

- Financial support from city or county government: 7.0
- College work-study students and college volunteers: 6.9
- A sliding fee or volunteer hours supplied by parents: 6.5
- Cultural groups daily supplying artists and music instructors: 6.1
- High school students doing community service every week: 6.1
- A specific portion of a person's time donated by two or three youth servicing organizations (e.g., YMCA or 4-H): 6.1
- A corps of senior citizens who help every week: 5.7
- One of the items partially funded the United Way: 4.9

All the items inventoried were rated 4.9 and above, indicating they were important with the top two items (in-kind resources and half-time paid staff) rated "critical" with a statistically significant difference from the remaining items on the list. Experience from respondents also conveyed that if an afterschool program is operating from one grant, and it does not involve partners from inside and outside of schools, then the program will most likely terminate when the grant runs out. Missing from this survey was the student perspective, arguably the keenest viewpoint and certainly the most valuable stakeholder experience in the system.

Quality Programming: Supervision and Structure, Well-Prepared Staff, and Intentional Programming

Quality OST programming has many layers and should have clear goals. Oftentimes the grant supporting the program has data-driven targets that drive increasing expectations academic outcomes and accountability (Surr, 2000). Typically, afterschool programming is initiated through grant support, where teachers (experts of learning and content-focused) are paid to stay afterschool to provide supervision, assist students with content-specific tutoring (often mathematics or ELA), and develop student study skills specifically in "high need" academic areas. Research shows disadvantaged students benefit the most from participation in academically oriented afterschool programs (Harris, 2004; Mahoney, Lord, & Carryl, 2005; Miller, 2001; Welsh, Russell, Williams, Reisner, & White, 2002); however, the majority of all evaluated and researched programs involve student participants from low-income backgrounds (Scott-Little et al., 2002). While afterschool programs may try to create a relaxed and nurturing setting that offers choice for adolescent youth (different from the in-school environment), at the end of the day it is school-like activities extending beyond the school day to reach academic targets and disengaging for the student learner. Adults are observed as in control of the learning environment—similar to what is typically experienced in the classroom with the greatest of intentions to be accountable for academic outcomes on high-stakes testing. Intention for academic accountability leaves little room for shared visioning between student and adult for the afterschool environment.

Garnering Support Through Partnerships

Recruiting and convincing students to participate regularly in afterschool programs is a challenge (Lauver & Little, 2005). While exposure to new experiences and homework support in a safe and supervised environment may be alluring to elementary and some middle school age children, older teens will often want to know that it will lead to greater educational and employment opportunities in their future—an outcome that benefits entire communities and economies. Once a program establishes regular attendance, evidence of success and achievement can help sustain program support and funding, but it is not sufficient (Peterson, 2004). Diversified funding streams that include grants, funding from local school district, city, and and/or United Way, in-kind contributions, volunteer support, corporate donations, and user fees are all often necessary, and how these entities are approached must be included in the visioning process for afterschool matters. Partnerships, collaboration, and trust between in-school and out-of-school resources are key and require continuous cultivation, a job that is often carried by an afterschool champion in the adult form. Value and passion for the programs are best conveyed by the student-stakeholders and should be shared with the broader community and decision makers, yet this point is often missing.

Partnering with Youth: Empowering Student Voice and Building Efficacy

For middle and high school students, it is not enough to have access, supervision, and structure in the afterschool program. For successful and sustainable programming, the partnership with middle school and high school students must gradually aspire to become 1:1 students:adults (including faculty, parents, other community organization partners, etc.)—where students are empowered to be engineers of their own learning environment. Yet adolescents cannot be expected to carry the full burden of empowering themselves and their communities,

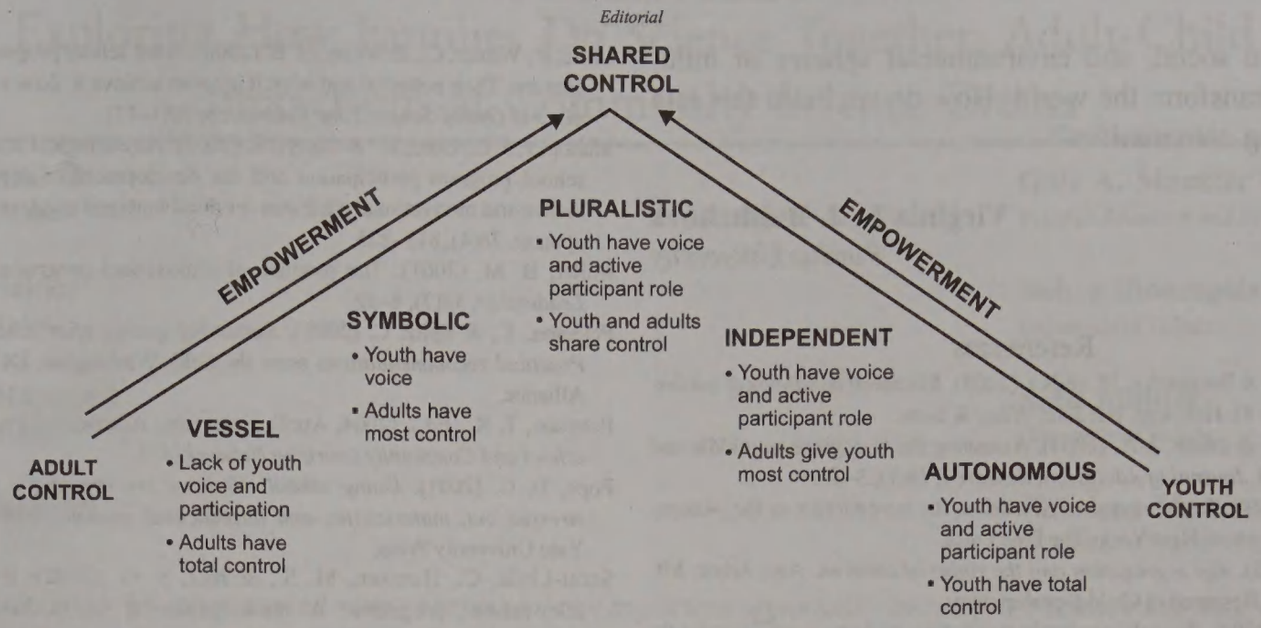

Figure 1. The TYPE Pyramid (Wong et al., 2010).

and that is where adults must share in this responsibility (Wong, Zimmerman, & Parker, 2010). The Typology of Youth Participation and Empowerment (TYPE) Pyramid uses an empowerment framework to describe various degrees of youth-adult relations that can be helpful when thinking about developing positive youth-adult partnerships that involves youth perspective and participation in the development of programs designed for them (Figure 1; Wong et al., 2010). Empowerment frameworks focus on enhancing wellness as well as personal and collective strengths, and identifying sociopolitical influences on quality of life (Wallerstein, 1992; Wallerstein & Bernstein, 1988; Zimmerman, 2000).

Critical consciousness is central to the empowerment process, as Freire (1970) notes that people are powerless when they are unaware of causes that shape their conditions, and that empowerment occurs through creation of a collective critical consciousness. Critical consciousness is achieved when "people develop their power to perceive critically the way they exist in the world with which and in which they find themselves; they come to see the world not as a static reality, but as a reality in the process, in transformation" (Freire 1970, p. 83). Freire suggests that empowerment is a result of an awareness that is formed when individuals understand how their circumstances are shaped by not only their own behavior, but also broader social and historical forces (Wong et al., 2010). Getting behind academically in middle school has broad implications for future career opportunities and quality of life—and such topics can be thoughtfully tied into youth focus groups to help develop solutions to the issues. By questioning these circumstances, youth and communities can uncover their own sense of agency and become empowered to cocreate innovative afterschool environments for learning. Hence, young people are uniquely positioned to make important contributions to afterschool program development, research, and be agents in their own personal and community development.

So where do adolescent afterschool programs currently fall under this pyramid (Figure 1)? Likely on the left-hand side (vessel, symbolic)—if an afterschool program exists at all. Evidence-based accountability is critical, especially for programs developing our youth. However, perhaps the types of evidence we account for in out-of-school programs should be different from what is collected in the classroom during the school day. Using an empowerment framework can be helpful in developing and evaluating youth-adult partnered programs, especially when considering academically oriented OST programming. Essentially, student voice must be at the center and cultivated as a codeveloper of the youths' afterschool space. Providing autonomy in a supportive environment builds youth self-efficacy that instigates the adoption, initiation, and maintenance of health promoting and sustaining behaviors (Schwarzer & Luszczynska, 2006), which ultimately contributes to the overall quality of life. Building youth efficacy into an afterschool programming starts with their perspective. It is not enough to be conscious and empowered; one must gain mastery experiences and resiliency to persist (self-efficacy) when faced with social and political barriers. Programs that not only empower but develop the youth's efficacy from

personal, to social, and environmental spheres of influence will transform the world. How do we build this into our learning communities?

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Exploring How Families Do Science Together: Adult-Child Interactions at Community Science Events

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Promoting family learning around science represents an important opportunity to reinforce science learning during out-of-school time. Evidence suggests that parent-child discourse around science can promote inferential thinking by children and help solidify their understanding of science concepts. While teacher professional development that promotes the type of discourse that encourages student inquiry is trending, interventions that assist parents in developing the same types of learning talk skills are scarce. In this descriptive study, family discourse was observed at a series of events at community centers that promote science learning, such as the zoo and the library. These events were part of a large-scale professional development program designed to transform teaching and learning around PK–3 science. Families were scored on their interaction, discourse, and use of "talk moves" using the Discourse, Interaction, and Inquiry in Family Science rubric. The results demonstrate that the events promoted family discourse and interaction in a manner dependent on the activity context. Implications for teachers and design of family science learning activities are discussed.

Science learning experiences are often thought of as a predominantly school-related endeavor, but this overlooks an important array of out-of-school learning experiences. On average, a person only spends about 5% of their lifetime at school, and only a small fraction of that is devoted to science instruction. Children spend most of their out-of-school time with their families, and the research literature suggests that parents' participation enhances children's academic achievement in many ways (Callanan, Shrager & Moore, 1996; Crowley, Callanan, Tenenbaum, & Allen, 2001). Informal science education settings such as science centers, zoos, parks, and planetariums can play a critical role in promoting science education outside of school by providing a venue for families to learn about science together (Falk & Dierking, 2010).

As an example of how families can facilitate child learning, Crowley et al. (2001) investigated examples of shared scientific thinking in everyday parent-child activities in families with children between the ages of four and eight in relation to a museum exhibit on zoetropes. Their analysis revealed that many parent-child conversations discussed scientific evidence in a sophisticated way, with a significant fraction of conversations highlighting evidence, comparing two kinds of evidence, or featured a parent providing an explanation that was causal (Crowley et al., 2001). The authors described these explanations as "explanatoids" because they were often brief and somewhat vague. These data showed that parents do encourage children's scientific thinking and can be effective facilitators in their child's science learning. In fact, children who were provided the "explanatoids" were more likely to develop a conceptual understanding of the phenomena at play (Fender & Crowley, 2007).

Crowley and his colleagues' research regarding parent-child interactions and conversations inform the design of informal science-learning experiences. As their data demonstrated, parental explanations can be vague and fragmented, and parents may fall into a natural teacher-like role rather than actively participating in the investigations with their children (Crowley et al., 2001; Fender & Crowley, 2007; Shine & Acosta, 1999). Parents may also be more likely to try and give their children simple tasks to complete while they take on the more cognitively challenging tasks such as making inferences (Gleason & Schauble, 2000). However, Allen and Gutwill (2009) suggested that careful design of family science learning

experiences can encourage parents to take on a more coinvestigatory role. If family members are provided specific reasons to collaborate, the participation of all members is enhanced (Kaya & Lundeen, 2010). Conversation or joint verbal engagement between parents and children plays a vital role in meaning making and scaffolding learning during these types of informal science learning experiences (Leinhardt, Crowley, & Knutson, 2002).

For children to successfully ask questions, carry out investigations, construct explanations, and build and use models, as recommended by the National Research Council (2012), they need to develop inferential thinking skills. Parents can promote such inferential thinking by asking open-ended questions (e.g., what, why, and how questions) that allow children to express their own thoughts and ideas in relation to an object or activity. Parents, however, should not be expected to have this knowledge as they enter an exhibit space within an informal learning space or when they participate in an activity.

Despite many findings supporting parental involvement, few families emphasize science with their children (AAAS, 2001; Calabrese-Barton, Drake, Perez, Louis, & George, 2004), and families are oftentimes uncomfortable in their own understanding of science (Calabrese-Barton et al., 2004; Shymansky, Yore, & Hand, 2000). Exhibits and activities need to be designed in a way that quickly communicates to the parent their support role and provides enough information to the parent that they can successfully scaffold the experience for their child (Gaskins, 2008).

Engaging in the type of adult/child discourse that emphasizes scientific inquiry and exploration does not come naturally. While teacher professional development that promotes the type of discourse that will encourage student inquiry is trending, interventions that assist parents in developing the same types of learning talk skills are scarce.

Background to the Current Study

The context for this study is a large-scale early childhood science project for teachers and families of preschool through grade 3 (PK–3) children, NURTURES. Designed around the Harvard Complimentary Learning Model (Harvard Family Research Project, 2008), NURTURES partners a university, local urban public school district, day care centers, and community informal science resources to transform science teaching in local PK–3 classrooms. The primary components of NURTURES include professional development for PK–3 teachers, family take-home science packs, and community science events for families (Sci-Fun events).

Activities at the Sci-Fun events were designed to encourage the entire family to be involved in scientific inquiry and discourse and were developed through collaboration between university science educators and informal science professionals. Event Guides navigated families through the activities at each event and included Talking Tips (suggestions for parents to encourage productive science talk at each activity). The Tips focused on specific Talk Moves (Michaels, Shouse, & Schweinburger, 2007) and on the science and engineering practices delineated by *A Framework for K–12 Science Education* (National Research Council [NRC], 2012). Talk Moves are conversational strategies designed to encourage children's reasoning and argumentation abilities and therefore their learning (Michaels & O'Connor, 2001). Elements from a project-developed instrument designed to assess the alignment of teacher inquiry practices in the classroom with NGSS (SCIIENCE) provided additional Talking Tips (Mentzer, 2014). In all, there were 10 tips that could be observed:

From Talk Moves:

1. Re-voicing what the child said.
2. Asking child to restate someone else's reasoning.
3. Asking child to apply his/her own reasoning to someone else's reasoning.
4. Prompting child for further participation.
5. Asking child to explicate his/her own reasoning.
6. Using wait time.

From SCIIENCE:

7. Encourage your child to extend what they learn to other situations.
8. Encourage your child to observe.
9. Encourage your child to make predictions.
10. Encourage your child to figure out how to solve a problem.

This study examined how parents and children interacted during Sci-Fun activities, and to what extent parents incorporated talk moves and practices from the *Framework* (NRC, 2012) into those discussions.

Methods

Sample

The sample consisted of 101 families observed at a total of nine different activities during five separate events in 2015 and 2016 (the zoo, the space center, the science museum, a local park, and the library). Permission to observe was asked prior to scoring. Observers placed themselves outside of the family engagement but close enough to see and hear what occurred. In addition, family demographics were collected when permission to observe

Table 1
Family Science Observation Demographics

Age	Male	Female	Mother	With Sibling	Father	With Sibling	Both Parents	With Sibling
3	0	1	1	0	1	0	1	0
4	6	4	6	2	2	1	2	2
5	11	6	11	3	3	0	3	1
6	14	10	18***	6	4	3	5	3
7	10	14	15	2	7	0	9*	2
8	6	7	11**	5	2	0	3	1
9	3	3	2	0	3	1	1*	0
Totals	50	45	64	18	22	5	24	9

Note. *One is a grandmother. **Two are grandmothers. ***Three are grandmothers.

was granted. Family interactions between the target aged child (3–9) and parents/siblings were observed. Table 1 provides demographics sorted by the age of the targeted child. The dotted lines in the table show when the parent was accompanied by an older sibling.

Overall, a total of 50 boys and 45 girls were observed along with their families. Mothers alone or with siblings were the most commonly observed although all family configurations were present including a few that included a grandparent.

Observation Rubric

The project developed "Discourse, Interaction, and Inquiry in Family Science" observation rubric (DIIFS) was designed to establish an understanding of how families experienced the Sci-Fun events by examining family interaction and discourse. It included items from Talking Tips and a gauge of family interaction level to determine to what degree parent/child worked cooperatively. The interaction was scored as following: (3), balanced (interaction between adult and child resulted in a balanced endeavor between adult and child); (2), moderately balanced (interaction between adult and child is more one-sided than balanced, adult or child may spend some time unengaged or simply following/watching); (1), unbalanced (either child or adult is not engaged at all). An overall interaction ranking as well as rankings for the specific phases of scientific investigation recorded: exploration/ design, building/constructing, testing, and redesign.

Family discourse was also scored overall and by element as the following: (3), open-ended questions asked and child provides detailed responses; (2), mostly adult asks open-ended questions though child may not offer detailed responses; (1), mostly closed-ended question/ answer (closed questioning); (0), no discourse. A checklist for each section included relevant Talking Tips to triangulate data. A notes section of the rubric provided qualitative support for the rating. Finally, observers noted when adults used one of the twelve Talk Moves described above.

Inter-rater reliability (IRR) was established through the rating of a series of three video recordings of families engaged in Sci-Fun activities from previous years. Lights's kappa (1971) where Cohen's kappa is calculated for all possible pairs of coders and then the arithmetic mean is calculated to provide an IRR coefficient was used to examine IRR. The resulting kappa for raters using the DIIFS in this study was 0.79.

Total number of families observed per event was dependent upon the amount of traffic as well as how long it took a family being observed to complete the activity. Some activities were more complex than others. For example, at one activity held at the zoo, families were asked to observe bats in a dark area and then move to another location and observe a bird. Their goal was to note differences and similarities between the two animals. This event, on average, took about 10 minutes. On the other hand, a more complex activity at the science museum asked families to build a tower from newspaper that could withstand a force of wind from a fan. They received points for height of structure as well as its stability and scores were posted on a chart. Families at this activity were encouraged to first design and then build their structure, test it, and then make modifications to improve its performance. Some families were engaged at this activity for up to 45 minutes. In general, the number of families observed at one activity during an event ranged from six to fifteen within a four-hour period.

Results

During this study, nine activities were observed—two at the local park (March 2015), three at the local zoo (May 2015), two at a space center (October 2015), one at a library (January 2016), and one at a science museum (February 2016). Of the nine activities, four offered exploration only.

Four activities provided opportunities to engage in all four phases (explore/design, build, test, redesign). The ninth activity was a collection of 13 small investigations that included a mix of the elements. At this particular activity (Mini Micronauts), families were encouraged to engage in any of the investigations that interested them; most families did not complete all 13.

Interaction Data

Table 2 provides the frequencies of interaction levels of phases by activity (the letters A and C indicate whether the adult or the child dominated the interaction). It should be noted that although activities offered the opportunity to engage in multiple elements of investigation, some families moved on before completing all phases so totals in each element may not match (e.g., Foam Rockets where $n = 10$ for exploration but $n = 8$ for redesign).

The overall rating is weighted in the sense that it is dependent upon the amount of time the family spent engaged in the phases rather than simply averaging of scores. So, e.g., while two families were observed at a level 3 for the exploration phase of the Stream activity, the overall score saw only one of those families at a 3 because the family that moved to a child dominated "2" spent more time during the building phase where interaction was less balanced. This is a judgment the observer makes when awarding an overall score and is based upon notes indicating time and depth of experience at each phase.

It is clear from Table 2 that across events, activities, and different parts of activities, the observed families were having conversations about science, indicating that the Sci-Fun events provide a framework for family discourse around science. This naturally leads to the question of who is doing the talking. The overall interaction scores indicate that, in the observed families that received this score, talk is largely balanced between adult and child. Seventeen families (17%) scored a 1A or 1C, indicating one-sided interactions during the activity. However, 33 (34%) of the families were scored as 3, indicating that a significant proportion of families had well-balanced interactions at these events. The remaining 48 families (49%) were characterized by interactions that were dominated by one party but not one-sided, with the majority of those being dominated by the adult.

Table 2 shows that during the Explore/Design phase as well as for the overall experience interactions between adults and children were mostly balanced, or some adult dominance was present (typically in the form of providing instructions and keeping the child on task). During the Build phase, the balance shifted to more adult supervision

Table 2
Summary of Interaction Scores

	Exploration/Design				Building				Testing				Redesign				Overall			
Activity	1A	2A	3	2C	1C	1A	2A	3	2C	1C	1A	2A	3	2C	1C	1A	2A	3	2C	1C
Park																				
Habitats ($n = 8$)		4	4														4	4		
Owl Pellets ($n = 7$)	1	3	1		1											1	3	1		1
Zoo																				
Goats ($n = 10$)		1	8	1													1	8	1	
Birds & Bats ($n = 10$)	3	5	2													3	5	2		
Stream ($n = 10$)			2	3	5			1	3	2				1				1	4	5
Space Center																				
Mini Micronaut ($n = 7$)		6	1			1	4					3	3	1						
Foam Rockets ($n = 10$)		5	3	2		2	4	4			1				2	1	1	6	2	1
Library																				
Pizza Box Maze ($n = 19$)		6	6	5		2	7	6	4			1	5	10	2	1	1	2	2	4
Science Center																				
Paper Towers ($n = 18$)	1	1	1	1	1	2	7	5	4		3	2	3	7		2	2	3	1	
Totals	5	31	28	12	7	7	22	15	11	2	4	6	11	17	4	4	4	4	6	3
																3	5	6	4	
																11	33	33	15	6

Table 3
Overall Discourse Ratings

	Discourse Level			
Activity	0	1	2	3
Park				
Habitats ($n = 8$)	0	0	3	5
Owl Pellets ($n = 7$)	1	4	2	0
Zoo				
Goats ($n = 10$)	0	1	2	7
Birds & Bats ($n = 10$)	0	4	1	5
Stream ($n = 10$)	5	4	1	0
Space Center				
Mini Micronaut ($n = 7$)	0	2	3	2
Foam Rockets ($n = 10$)	0	3	3	1
Library				
Pizza Box Maze ($n = 19$)	1	7	6	5
Science Center				
Paper Towers ($n = 18$)	2	12	3	1
Totals	9	37	24	26

but during Test and Redesign, the observed interactions were spread across the scale.

Discourse

As with interaction levels, discourse was measured with the DIIFS during each phase of the observation. In addition, an overall discourse score was assigned based, again, on discourse over the entire time the family was engaged in the activity. This means that the overall discourse score is not simply an average but considers the amount of time spent at each level. Table 3 shows the overall discourse levels for the study sample. Looking at the scores across all events, families were evenly split between low-to-no discourse and extensive discourse (46 families with an overall score of 0 or 1 compared to 50 with an overall score of 2 or 3). However, when examining individual activities, it is clear that some were much more successful in engaging families in meaningful discussions about science than others. For example, the Habitats, Goats, Birds & Bats, and Pizza Box Maze activities saw a higher number of families engaged at level 3 while Owl Pellets, the Stream, Foam Rockets, and Paper Towers had little if any level 3 discourse.

A closer examination of observation notes provided more insight as to factors contributing to the scores. Observation notes from the Pizza Box Maze activity indicate that many families spent significant time planning, building, and testing their mazes together. Building the mazes was challenging but accessible for children, giving adults space to guide their children through the process, facilitating balanced talk between adults and children. In contrast, during the Foam Rocket activity, adults in general took over the building of the rocket. There was no design involved as families received a kit along with instructions. When testing began, the children frequently ran off and shot the rockets a few times but no discussion about how the rocket might go further or even the science behind the rocket's propulsion took place. One might think that something similar occurred during the Owl Pellets but observation notes indicated that there actually was quite a bit of advanced discourse—but it was not at the family level. The facilitator at this activity enjoyed working with children. As a result, the adults of the family were delegated to observing what was occurring between the facilitator and the child.

On the other hand, the Stream activity consisted of a simulated stream where families were to build dams to divert the water. The children quite literally "dove" into the activity but most adults stood back, not wanting to get wet. Linking the observation notes with the discourse and interaction levels provided a clear picture of the family experience and, in the case of the Stream activity, a child-dominated activity with little discussion between adult and child.

Talk Moves

To facilitate comparison across different Sci-Fun activities, this section focuses exclusively on two engineering activities that featured Design, Build, Test, and Redesign phases. Talk moves from the Pizza Box Maze activity are presented in Figure 1. Notable about these data are the variety of talk moves that adults used. Eight different talk moves were observed during the Design phase and seven during the Build phase. The Test and Redesign phases, which saw less discourse overall, also contained fewer talk moves. Notably, the talk move "encourages child to investigate further," which was featured in this activity's page in the event guide, was used extensively, throughout all four phases, and by 12 of the 19 families.

Two other talk moves were used in each of the four phases. These were both talk moves that prompt a child to keep talking: repeating the child's statement and using wait time. Both of these moves were featured in a page of the event guide titled, "Talking and listening are at the very heart of learning," which encouraged adults to use these moves to promote their child's science learning.

Certain talk moves were specific to certain phases of the activity. For example, the Design phase was the only one that saw use of the talk move, "asks child to predict," which, of course, precedes an investigation, along with "asks child to explain thinking." Additionally, the Test

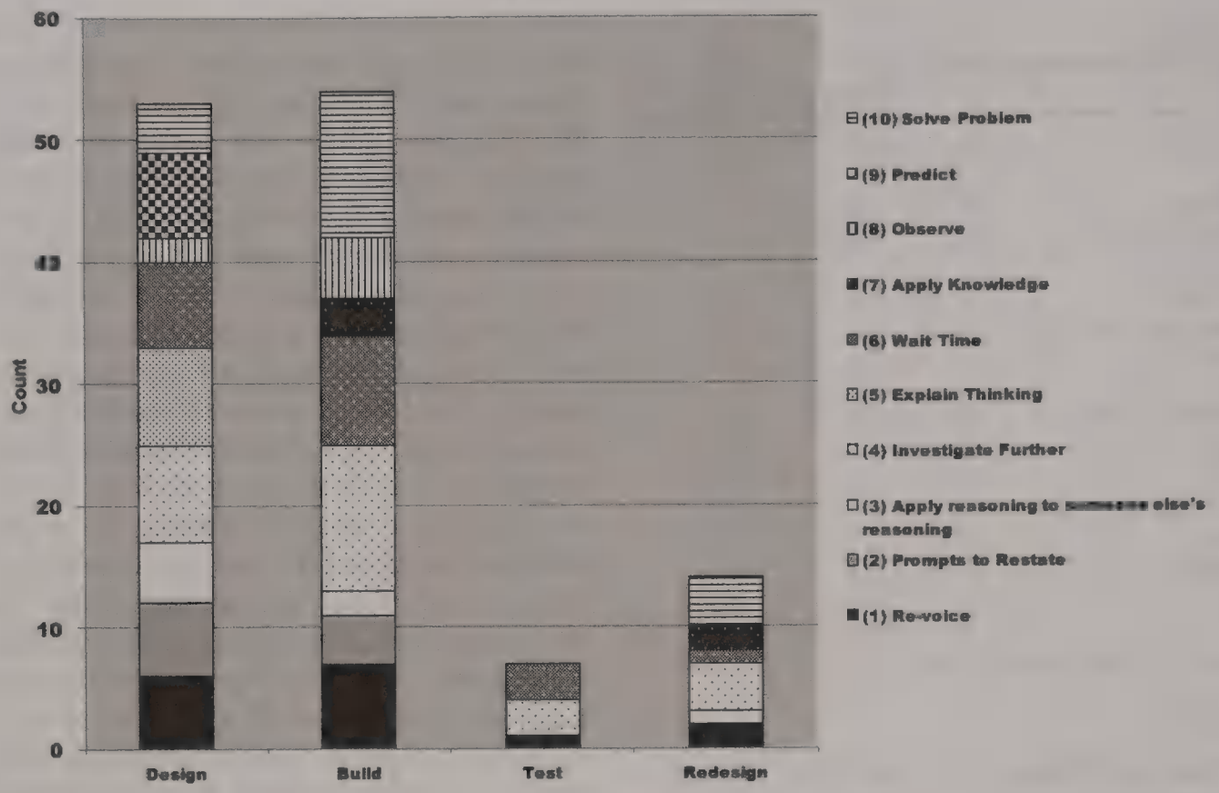

Figure 1. Talk moves used by families during the Pizza Box Maze activity.

phase, in which the fewest talk moves were observed overall, featured 13 families using the talk move, "prompts child to explain why a particular outcome occurred."

These data can be contrasted with the talk moves observed during the Paper Tower activity (Figure 2). Fewer talk moves were observed in this activity overall, and only

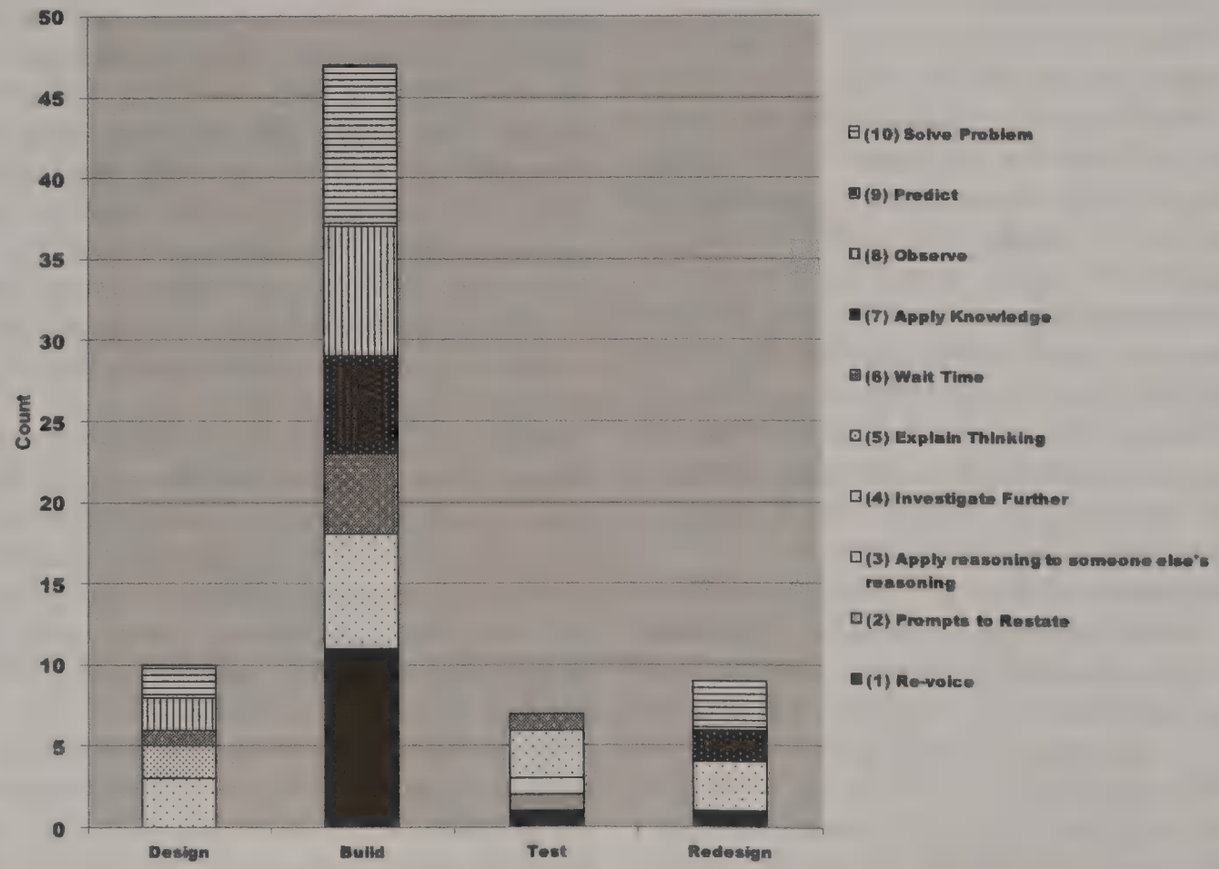

Figure 2. Talk moves used by families during the Paper Towers activity.

one ("encourages child to investigate farther") throughout all four phases, albeit at low levels. Here, the Build phase had the largest number of talk moves, with six. Some of the difference can be accounted for by the fact that, in contrast to the Pizza Box Maze, most families did not complete a Design phase—they went straight to building. The featured talk move for this activity, "asking child to explain thinking," was only seen in the Design phase. The two talk moves that prompt a child to keep talking ("repeating the child's statement," and "using wait time"), which were featured in the event guide again, each appeared in three of the four phases.

Most talk moves (and highest scores for discourse) occurred in the Build phase of the activity. Six talk moves were observed. In particular, "asks child how to solve problem," "asks child to explain observations," and "encourages child to investigate further," were used by a significant fraction of families.

Discussion

This analysis indicates that families are participating in science and engineering investigations and conversations that align to the *Framework* (NRC, 2012). Taken together, 83% of observed families scored an overall 2 or 3 for interaction, indicating that both adult and child discussed their progress throughout the activity. This contrasts with the dominant pattern of interaction previously observed at children's museums (Downey, Krantz, & Skidmore, 2010; Wood & Wolf, 2010), in which parents generally stepped back and let their child direct the play, occasionally intervening to help relieve frustration. Unlike some exhibits at children's museums, at which adults may be unclear about the role intended for them (Downey et al., 2010), the Sci-Fun events were developed with a specific role for the adult—as navigator of the event for their child, including scaffolding to direct their navigation (Hapgood, Strickler-Eppard, & Johnson, 2016). Such a design appears to facilitate family conversation. With a clearly defined role as a navigator—and not an expert—along with the necessary scaffolding to fill the role, events such as these may give adults a positive experience that could work to counteract the negative personal experiences and low self-efficacy that some adults feel about science (Calabrese-Barton et al., 2004; Shymansky et al., 2000), as in Kaya and Lundeen (2010).

Our results further described those family conversations. The majority (52%) of families showed overall discourse scores of 2 or 3, indicating that their conversation included some open-ended questioning with some questions leading to extended responses by the child. This, coupled with the interaction scores, depicts an event in which adults and children engineer something together, with adults facilitating the children's learning through questioning.

Family discourse is not confined to questions and answers. Analysis of the talk moves indicated that adults use a wide variety of strategies to scaffold science activities for their children. These include techniques that help adults deepen conversation (wait time, revoicing), use tools from science inquiry (asks child to make a prediction or investigate further or describe observations), and encourage children to think critically (asks child to explain their thinking or transfer knowledge to a new situation). Furthermore, adults spread out the discourse by asking a variety of questions early in the activity, while the children are more likely to dominate interactions in the Test and Redesign phases. While our analysis reveals more conversation than observed by Wood and Wolf (2010), this pattern of scaffolding by adults is a common link between the two.

This work complements extant literature demonstrating that simple interventions can increase family conversation at science museums (Allen & Gutwill, 2009; Benjamin, Haden, & Wilkerson, 2010). As Meade (2009) described, engagement strategies that are chosen for a family learning experience need to encourage adults and children to learn together and should involve clear outcomes for all members of the family. In this case, the intervention consisted of an event guide that was designed to encourage adults to converse with their child during the activities. While this study does not establish causality, several results suggest that adults did model their behavior on suggestions from the event guide. First, families generally, though not exclusively, followed the Explore/Design-Build-Test-Redesign pattern suggested in the event guides. Second, adults frequently used talk moves appropriate to the phase, such as asking children to predict during Design, or to explain what happened during Test. And finally, adults used talk moves specifically highlighted in the event guide during the observed event.

These results have implications for educators seeking to facilitate family learning experiences. First, the activity context can enhance or restrict participation by adults. The Stream activity, which scored low in interaction and discourse, likely hindered adult participation by creating the obstacle of getting wet. We stress that this does not mean that such activities should be avoided, as child-centered exploration has an important role in science learning, but rather that activities seeking to promote family science learning may face a barrier by including such elements.

In addition, activities that featured a closed-ended task, such as the Foam Rockets, in which families received a kit with instructions, saw lower scores for discourse and interaction than more open-ended tasks, such as the Pizza Box Maze. The more open-ended tasks appeared to create more opportunity for adults and children to discuss while working to achieve a mutual goal. Just as noted by the *Framework* (NRC, 2012), opportunities for learning are richer during inquiry sciences experiences than in "cookbook" science activities with a known conclusion. Adults and children will have more to discuss when navigating an unknown pathway together.

Finally, the Owl Pellets activity is instructive when considering the role of facilitators for family science learning activities. During this activity, interaction and discourse scores were low because an enthusiastic facilitator did most of the talking. Therefore, during activities specifically designed to promote family learning, facilitators should be trained to provide support in specific ways, such as highlighting the goal for the activity or providing additional materials.

These results have implications for teachers who design homework and plan field trips that may include time for family learning. Teachers may want to carefully consider how to provide opportunities for adults and children to learn together during a field trip, rather than relying on a facilitator or teacher exclusively for information. They can accomplish this with guiding questions that spell out a clear role for the adult and offer opportunity for conversation, rather than a prescriptive or step-by-step approach to a problem or exhibit.

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An Exploration of a Quantitative Reasoning Instructional Approach to Linear Equations in Two Variables With Community College Students

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In this exploratory study, we examined the effects of a quantitative reasoning instructional approach to linear equations in two variables on community college students' conceptual understanding, procedural fluency, and reasoning ability. This was done in comparison to the use of a traditional procedural approach for instruction on the same topic. Data were gathered from a common unit assessment that included procedural and conceptual questions. Results demonstrate that small changes in instruction focused on quantitative reasoning can lead to significant differences in students' ability to demonstrate conceptual understanding compared to a procedural approach. The results also indicate that a quantitative reasoning approach does not appear to diminish students' procedural skills, but that additional work is needed to understand how to best support students' understanding of linear relationships.

Recommendations made by the American Mathematical Association of Two Year Colleges (AMATYC) call for community college instructors to teach mathematics "in the context of realistic, understandable, applied problems that help students develop an appreciation of the nature, history, and usefulness of the discipline" (Blair, 2006, p. 10). The underlying goal is for students to understand mathematics, develop problem solving skills, and develop conceptual understandings (Blair, 2006, p. 6 & p. 54).

Similar principles and standards for teaching mathematics are called for more broadly in the mathematics education community (Leinwand, Brahier, & Huinker, 2014). Citing classroom research from the last 30 years, Leinwand et al. (2014) assert that mathematics teachers should engage "students in solving and discussing tasks that promote mathematical reasoning and problem solving" (pp. 10–11). Moreover, Leinwand et al. identified two strands that constitute mathematical proficiency: conceptual understanding and procedural fluency, where procedural fluency is to be built upon "a foundation of conceptual understanding so that students, over time, become skillful in using procedures flexibly as they solve contextual and mathematical problems" (Leinwand et al., 2014, pp. 9–10).

But how can community college mathematics instruction be structured to effectively teach quantitative problem solving? Research suggests using an instructional approach with a focus on students learning how to identify quantities in real-world situations and how to reason with these quantities to produce new quantities (Carlson, Oehrtman, & Moore, 2013; Ellis, 2007a; Lobato & Thanheiser, 2002; Simon & Blume, 1994; Thompson & Thompson, 1992) Others have made the case for how understanding, identifying, and reasoning with quantities is foundational to all mathematics, especially in developing the mathematical ways of thinking needed to solve mathematical problems encountered in real life, as well as within mathematics and other disciplines (Dougherty & Zbiek, 2010).

Further, there is broad consensus that conceptual knowledge supports procedural knowledge but there is still debate about what order procedural knowledge and conceptual knowledge should be taught (Rittle-Johnson, Schneider, & Star, 2015). For example, Schwartz and Martin (2004) showed that conceptually based activities are effective for preparing students to learn from lectures and other learning resources. However, other research shows children first learn procedures for solving problems and then after repeated practice solving problems extract conceptual knowledge (Fuson, 1988; Karmiloff-Smith, 1992; Siegler & Stern, 1998). Still others have shown that the teaching and learning of conceptual understanding and procedural skill build on each other in an iterative or cyclical process (Rittle-Johnson & Siegler, 2001).

Purpose of This Study

This study examined an experimental model of instruction for teaching linear equations in two variables that focused on using real-world contexts, developing students' mathematical reasoning skills with quantities, and

building procedural fluency upon a foundation of conceptual understanding (hereafter called a *quantitative reasoning approach*). An intervention group was taught a unit on linear equations in two variables using a quantitative reasoning approach, and a comparison group was taught a unit on the same topic using a *traditional procedural approach*, which emphasized learning and practicing step by step solution methods to solving routine problems. Data were collected on a common unit test for the two groups to determine:

1. What does the comparison of unit assessment data between the two instructional groups indicate about the relationship between conceptual knowledge and procedural knowledge in the teaching of mathematics to community college students?
2. How does the mathematical performance and reasoning ability for students in the two instructional groups compare?

Background

Quantitative Reasoning

Following Thompson and Thompson (1992), we use quantity when referring to an individual's conception of a measurable quality of an object or event. A quantity consists of an object or event, a quality of the object or event, an appropriate unit or dimension, and a process for assigning a numerical value to the quality (Thompson, 1994). Measurement of a quality (or attribute) involves making a multiplicative comparison between the quality of interest (such as the width of a rectangular floor) and the unit (such as a meter). However, making a direct measurement is not necessary to conceive of a quantity. This is because "quantities are constituted in people's conceptions of situations, rather than the objects or situations themselves" (Ellis, 2007a, p. 440).

Simply put, quantitative reasoning is reasoning about things and their attributes (Thompson & Thompson, 1992). Two types of quantitative reasoning relevant for beginning algebra students learning about linear equations in two variables are: covariation reasoning and correspondence reasoning (Jacobson, 2014). Covariation reasoning involves analyzing how two quantities vary in tandem, while correspondence reasoning involves identifying a functional relationship between two quantities. Both forms of reasoning are crucial to developing an understanding of function. Covariation reasoning is used to examine how one quantity changes in relation to changes in another quantity. Correspondence reasoning is used to determine how one quantity can be determined by the other. In the case of linear functions, noticing that two quantities covary with a constant rate of change is an important aspect of understanding the slope-intercept form of a linear equation (Carlson, Jacobs, Coe, Larsen, & Hsu, 2002; Jacobson, 2014).

Students deficient in quantitative reasoning are poor at algebraic problem solving (Thompson, 1988). When students name quantities by their numerical value only instead of by the name of the measurable quality of the object (e.g., "100 dollars" instead of "Paul's savings") they do not distinguish between the quantity and its measure. This leads to difficulty identifying quantities that have an unknown value and deciding which operation to perform when determining a third quantity.

Comparing quantities multiplicatively to form a ratio is another special type of quantitative reasoning called proportional reasoning. Ratios are formed to measure how many times larger or how many times smaller a quantity is than another (multiplicative comparison), or the intensity of a quantity compared to another (composed unit) (Lamon, 2012). A ratio-as-measure task requires students to identify a ratio as an appropriate measure of a given attribute and to create that ratio (Simon & Blume, 1994). When a ratio is not given at the outset but rather is developed by the classroom as a useful mathematization of the situation, greater understanding of the quantity and of ratio are likely to result. When students are given a ratio as a measure of a given attribute they do not necessarily see a need for a ratio to measure the attribute and why the ratio is appropriate. As Harel's (2001) Necessity Principle asserts, students are most likely to learn if they see an intellectual need for what we intend to teach them.

Using ratios as measures can be a difficult transition for students (Lobato & Thanheiser, 2002; Simon & Blume, 1994; Smith et al., 2013). Students may struggle to isolate attributes in a situation that a ratio measures from other attributes (Lobato, Ellis, & Charles, 2010, p. 23; Lobato & Thanheiser, 2002). Students may also struggle with using ratios to compare attributes. For example, research shows that students struggled to know whether changing the length of the platform at the end of a ramp affected the slope of the ramp or not (Lobato et al., 2010). On the other hand, Ellis (2007a) found that when a group of middle school students focused on quantities in real-world contexts instead of numbers in tables, they searched for a new relationship between the quantities, experienced the necessity to create a ratio as a measure, and understood the ratio remains constant even when the quantities changed. Ellis (2007a) named reasoning leading to the construction of a ratio as emergent-ratio quantitative reasoning.

A Quantitative Reasoning Approach

A quantitative reasoning approach to instruction includes exploring with students how changing quantities affect an emergent quantity, giving students time to reflect on a problem's context, and helping students identify a quantity by the name of the measurable attribute. Simply placing students in a quantitatively rich situation does not necessarily guarantee students will develop correct understandings of the concepts (Ellis, 2007a; Moore & Carlson, 2012). Instead, the type of quantitative reasoning students engage in is what results in productive mathematical understandings. Ellis (2007a) suggested students engage in activities such as: (a) exploring how changing one or both initial quantities will affect the emergent quantity, (b) determining how to adjust the initial quantities while keeping the emergent quantity constant, and (c) determining how to double, halve, or otherwise manipulate the emergent quantity in relationship to the initial quantity. Students also need to be clear and specific on what is being measured to eventually write meaningful expressions and formulas (Carlson et al., 2013).

Ellis (2007a) studied the use of a quantitative reasoning instructional approach by examining the generalizations of middle school students taught linear functions in two different learning and teaching environments. In the first environment, students were taught linear functions using an approach that emphasized number pattern finding from tables of linear data, procedures, skills, and direct computational questions and responses. In the second environment, students were taught linear functions using an approach that emphasized quantitative reasoning: i.e., exploring quantities and their relationships in two real-world situations about linear growth. Ellis (2007b) observed the work of seven students from each learning environment in the classroom and through interviews.

Students' generalizing actions and reflection generalizations were counted and placed into the categories of Ellis' generalization taxonomy (Ellis, 2007b). Two types of generalizations made by students are particularly relevant for our work: statements of continuing phenomena and a statement of global rules (Ellis, 2007b). Statements of continuing phenomena were statements made by the students identifying a dynamic property extending beyond a specific instance such as "every time x goes up 1, y goes up 5." A statement of global rules is a generalization of a relationship such as "If the rate of change stays the same, the data are linear" (Ellis, 2007b).

Although the number of global rules statements made by the number-pattern students was more than the number made by the quantitative reasoning students, analysis of the interview data showed that the correctness of the global rules statements favored the quantitative reasoning students (Ellis, 2009). The number-pattern students incorrectly generalized that a table of data representing a situation is linear only if the numbers down a column in the table increased or decreased by the same amount between rows. They appeared to make this overgeneralization because all the tables they examined had this uniform quality. When they encountered a nonuniform table that represented a linear situation, they struggled and declared it nonlinear. The quantitative reasoning students extended their understanding of linearity to both uniform and nonuniform tables that represented real-world situations. Interestingly, the quantitative reasoning students made a greater number of statements of continuing phenomena, attending to the covarying nature of the quantities (Ellis, 2007b).

Using a quantitative reasoning approach shows promise for developing students' algebraic reasoning skills. This exploratory study is an initial attempt to investigate the effects of such an approach in a community college setting.

Methodology

Participants & Design

The participants of this study ($n = 71$) were beginning algebra students at a community college in the northwest. Thirty-four of the participants were taught a unit on linear equations in two variables using a traditional procedural approach (comparison group) and 37 participants were taught a unit on the same topic using a quantitative reasoning approach (intervention group). The students were placed in the beginning algebra course based on their placement test score or by earning a C or better in a pre-requisite Prealgebra course. No further selection criteria were applied other than asking for voluntary participation in accordance with human subjects protocol. For the comparison group, 34 of the 48 enrolled students agreed to participate; 37 of the 50 enrolled students in the intervention group participated. The lead author was the instructor for both groups (the comparison group one semester and the intervention group the following semester). At the end of instruction (four days for each group) both groups took the same unit assessment with 10 items designed to assess procedural understanding (procedural items) and 10 items designed to assess conceptual understanding (conceptual items). The responses of the two groups on the unit assessment items were then analyzed to compare performance and reasoning ability between the comparison and intervention groups.

Instructional Approaches

Lessons were developed by the lead author who was experienced in using the traditional procedural approach but was using the quantitative reasoning approach for the first time. The lead author worked closely with the second author to develop lessons for the intervention group, and the third author provided feedback on lesson enactment early during the unit.

The traditional procedural approach consisted of the teacher explaining a step-by-step solution method to solving a routine noncontextual problem, demonstrating the solution method, and then having the students practice. For example, on the first day the instructor explained how to determine if values of the variables are solutions to a linear equation in two variables, then demonstrated how to replace the variables in the linear equation with their respective values, simplify the equation, and see if a true statement resulted. He then gave the students a different linear equation in two variables with different values for the variables and had the students practice the step-by-step procedure. See Belue (2015) for detailed lesson plans and learning objectives. The students were then assigned similar homework problems to practice outside of class using online course software. Problems for instruction and homework were based on a beginning algebra developmental math textbook (see Trigsted, Bodden, & Gallaher, 2014).

The quantitative reasoning approach consisted of the teacher explaining and helping students understand a quantity and linear equation in two variable concepts in real-world contexts and then engaging students in tasks on a worksheet to further develop reasoning ability. For example, on the first day the lesson began with the teacher explaining the four components of a quantity, giving an example of a quantity in the classroom (the length of the floor in feet), and asking students to identify other quantities associated with the floor. The teacher then led a discussion on attributes of the floor that are not quantities followed by the teacher walking across the floor of the classroom and having the class identify the quantities involved in the walking event. The teacher then introduced the terms variable quantity and fixed quantity. Finally, the teacher then walked across the floor again and had the students measure his walking rate. The students then wrote down the walking rate and worked through proportional reasoning tasks with the rate on their worksheets in small groups. These types of activities, involving physical demonstrations of concepts and using different types of reasoning (quantitative, proportional, correspondence, and covariation) continued through day three of instruction. The problems and exercises on the worksheet were based on curricula designed to engage students in different types of reasoning (see Carlson et al., 2013; Lappan, Fey, Fitzgerald, Friel, & Phillips, 2009). On day four the teacher conducted a review for the unit assessment which included addressing standard procedures for solving noncontextual problems like the ten procedural problems on the unit assessment.

Unit Assessment

A 20-item unit assessment, with 10 procedural items and 10 conceptual items, was constructed to compare performance between the two groups. The 10 procedural items were short answer questions designed to align with previous assessments in the course and had no real-world context. They were routine problems similar to the problems the comparison group encountered during class and were intended to assess the students' ability to perform a step-by-step solution process (memorizable) to answer the question. The 10 conceptual items, on the other hand, could not be answered by performing a step-by-step solution procedure and were intended to assess conceptual understanding and reasoning abilities associated with linear equations with two variables. They were 10 short answer questions about a real-world situation of a person filling a swimming pool with water at a constant rate. They required the student to first correctly identify constant and varying quantities, then construct tables, graphs, and equations that model the situation. Items 15 and 17 asked students to explain how these representations tell you the situation is or is not linear. Thus, these items required students to provide evidence of conceptual understanding and reasoning ability to completely answer the questions. Detailed rubrics for assessing students' work for the procedural and conceptual items were applied to both groups. (See Belue, 2015 for the complete list of assessment items, rubrics, and the development processes.) For example, the rubric for item 15 (asking how the table they constructed tells you the situation is linear) assigned a score of 0, 1, 2, 3, or 4 for different levels of specificity with respect to student reasoning exhibited by their written response. To earn a 4, students needed to give a correct explanation (using either covariation or correspondence reasoning) and make explicit reference to data in the table.

The assessment items and rubrics were initially developed by the first author, with the second and third authors performing expert reviews and offering feedback. It is beyond the scope of this exploratory study to pursue validity issues beyond the expert analysis of whether items were constructed to capture the intended reasoning by students (both procedural and conceptual). Rubrics were

developed in a similar fashion, relying heavily on the literature on quantitative reasoning to identify anticipated reasoning categories associated with the conceptual items.

Data Collection

Students in both groups had 75 minutes to complete the unit assessment. The 20 questions were graded by assigning the point values for each question as prescribed in the assessment rubrics (Belue, 2015) These raw scores were then used to perform the quantitative analysis. In addition, we used qualitative methods to analyze students' responses to questions 15 & 17. These two items provided an opportunity to assess students' conceptual understanding of connections between representations of linear functions and defining aspects of a linear relationship between two quantities.

Quantitative Analysis

Raw scores based on the rubric for each question on the unit assessment were converted to scaled scores. For example, if a student received a raw score of three points out of four for an item according to the rubric the score was changed to 7.5 out of 10, or 75% (since raw scores for each item varied from two to four points). Scaled score means were computed for each item and each instruction group to conduct an item by item analysis on the set of scaled score means. The set of scaled score means was then statistically tested using a two-tailed *t*-test to determine if the two population means (one for the comparison group and one for the intervention group) were the same. They were then statistically tested using a one-tailed *t*-test (if not the same) to determine if the mean of one population was greater than the other.

Qualitative Analysis

The qualitative analysis started with the lead author reading each student's response to items 15 and 17 on the unit assessment and sorting the responses into categories of similar explanations. This resulted in a total of 10 initial categories for item 15 and a total of 11 initial categories for item 17. The students' responses and initial categories of similar explanations were then examined again by all three authors to determine how they related to covariation and correspondence reasoning. Based on this analysis and the combining of initial categories that originally separated incorrect from correct responses, four final categories of student thinking about linearity emerged. Of interest was students' ability to make correct generalizations (i.e., global rules statements) about linearity and statements of continuing phenomena involving covariation reasoning (Ellis, 2007b). We based the coding on the types of reasoning involved in determining a linear relationship even though students' responses were not always completely correct. The following is a description of the four categories.

Covariation reasoning. Student responses in this category explained that the table or graph showed the pool filled at a constant rate using explicit references to the quantities involved in the given situation. For example, one student response placed in this category was "The table tells you it is a linear relationship by being consistent. For every 3 seconds, 1 gallon is added" and another student response was, "It is linear b/c for every gallon added the seconds go up by 3, the rate is always the same." These types of responses were considered correct global statements about linearity and statements of continuing phenomena involving covariation because they explicitly addressed how the two quantities changed together at a constant rate (Ellis, 2007b).

Correspondence reasoning. Student responses in this category explained that the table or graph showed there was an explicit rule that related the two quantities (volume and time). For example, a student response placed in this category was, "It is a constant growth that does not vary. The table shows this because no matter what you plug in for s, g will always be 1/3 of that." These types of responses used correspondence reasoning because they explicitly addressed how the quantities were related by a functional rule.

Beginning quantitative reasoning. Student responses in this category were somewhat superficial explanations of how the quantities in the situation were related (using indications of either covariation or correspondence reasoning). Students attended to the quantities but without specific reference to how the quantities were related. For example, a student response in this category was, "The table shows it is linear because as the seconds increase, so too does the value of gallons" and another student response was, "It is a linear relationship because as the time increases the number of gallons in the pool also increases." These types of responses did not explicitly attend to how the quantities were linearly related.

Nonquantitative reasoning. Student responses in this category explained that the situation was linear because the table or graph was constant but with no explanation of what feature associated with the table or graph was constant. For example, a student response in this category was, "It is a linear relationship because there are consistent measurements" and another student response was, "it is a linear equation because is constant." This category also included responses that explained the situation was linear because the graph was a straight line. For example, one student wrote "It shows it is a linear relationship because

Table 1
Procedural Item-Scaled Score Means and Standard Deviations

Unit Assessment Item Number: Description	Mean (Standard Deviation) Comparison ($n = 34$)	Intervention ($n = 37$)
1: Plot an ordered pair on the coordinate plane	.95 (.12)	.86 (.26)
2: Find unknown coordinates of equation	.90 (.20)	.93 (.16)
3: Determine if ordered pair is solution	.98 (.09)	.99 (.04)
4: Find the slope of a line through two points	.92 (.19)	.79 (.32)
5: Graph a linear equation using intercepts	.73 (.32)	.71 (.30)
6: Find slopes of line parallel and perpendicular	.91 (.25)	.78 (.34)
7: Determine slope and y-intercept of equation	.79 (.32)	.71 (.33)
8: Graph a horizontal line	.86 (.29)	.77 (.35)
9: Determine if parallel, perpendicular, or neither	.62 (.44)	.56 (.42)
10: Graph line given point and slope	.80 (.34)	.65 (.38)

the line is a straight line." These types of responses demonstrated no quantitative reasoning because they did not reference specific quantities in their explanations and did not show any evidence of covariation or correspondence reasoning.

The responses in these four categories were then analyzed and compared between the comparison group and intervention group to identify similarities, differences, and themes in the students' thinking about linearity. A test for proportions was conducted to determine if performance was significantly different in each of the four categories.

Results

A quantitative and qualitative analysis between the intervention and comparison group at the individual item level of the procedural and conceptual items on the unit assessment was conducted to compare the students' performance and reasoning ability.

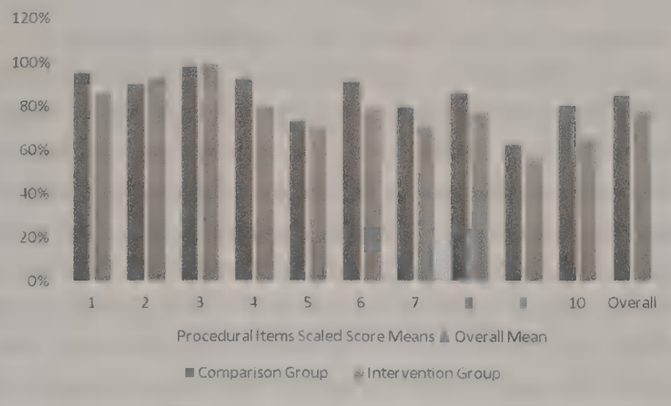

Figure 1. Procedural item-scaled score means and overall mean bar chart.

Quantitative Analysis

Procedural items. The scaled score means for each of the 10 procedural items for the comparison group and the intervention group are listed in Table 1. A brief description of each item is also included to illustrate the range of problem types. Notice that the comparison group ($n = 34$) had a 10% or greater scaled score mean than the intervention group ($n = 37$) on 3 of the 10 procedural items (items 4, 6, and 10). The comparison group and intervention group had about the same scaled scores (performance difference less than 10%) on the remaining seven procedural items. Both the comparison and intervention group had low scores (.62 and .56, respectively) on item 9. A two-tailed *t*-test conducted on the scaled score means of the 10 procedural items showed there was no difference in performance between the comparison and intervention group ($p > .05$) (Figure 1).

Conceptual items. The scaled score means for each of the 10 conceptual items for the comparison and intervention groups are listed in Table 2. A brief description of the conceptual items is provided to illustrate the range of problem types. All problems were tied to a single contextual situation involving filling a pool with water. The intervention group ($n = 34$) had a 10% or greater scaled

Table 2
Conceptual Item-Scaled Score Means and Standard Deviations

Unit Assessment Item Number: Description	Mean (Standard Deviation) Comparison ($n = 34$)	Intervention ($n = 37$)
11: Identify fixed quantities in a situation	.54 (.30)	.85 (.27)
12: Identify variable quantities in a situation	.43 (.27)	.54 (.26)
13: Create table of values for a situation	.50 (.39)	.70 (.31)
14: Determine if a situation is linear	.94 (.20)	.89 (.32)
15: How does table tell you situation is linear?	.43 (.35)	.58 (.36)
16: Create a graph that models situation	.58 (.33)	.73 (.27)
17: How does graph tell you situation is linear?	.36 (.36)	.59 (.30)
18: Construct linear equation for situation	.48 (.32)	.64 (.17)
19: Explain numbers and variable in equation	.40 (.27)	.59 (.22)
20: Identify and explain quantity in situation	.21 (.23)	.64 (.36)

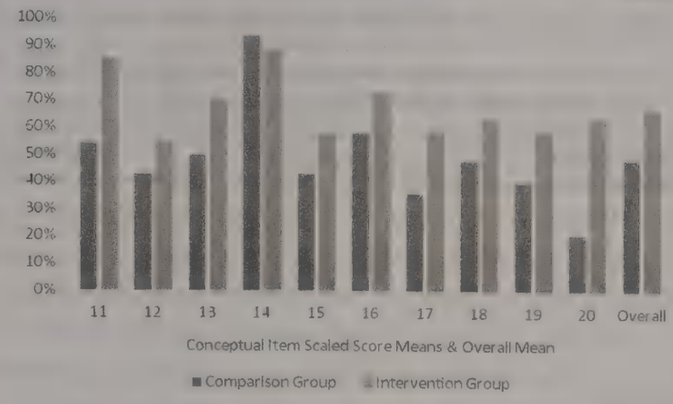

Figure 2. Conceptual item-scaled score means and overall mean bar chart.

score mean than the comparison group ($n = 37$) on 9 out of 10 of the conceptual items (11–13, and 15–20). A two-tailed t-test conducted on the scaled score means of the 10 conceptual items alone showed there was a difference in performance between the comparison and intervention group ($p < .05$). Further, a one-tailed t-test on the scaled score means of the 10 conceptual items showed the intervention group performance was greater than the comparison group ($p < .010$) (Figure 2).

The greatest differences in scaled score means on the conceptual items were a 43% greater mean on item 20, 31% greater mean on item 11, and a 23% greater mean on item 17. The distribution of the scaled scores for each of these items and for each instructional group is displayed in Table 3 via quartile scores. On item 11, at least 50% of the intervention group had a scaled score mean that was 1.0 compared to less than 33% of the comparison. On item 20, at least 50% of the intervention group had a scaled score mean that was .75 or greater compared to less than 33% of the comparison. For each item, the median scaled score mean was greater for the intervention group compared to the comparison group. The greatest difference was the difference in medians for item 11, which had a difference of .67.

Item 14 was the only item where the comparison group and intervention group scored the same. Items 20 and 17 were the first and second most difficult conceptual items for students respectively (item 20 had a combined score of .43 and item 17 had a combined score of .48). Item 12 also had a low combined scaled score of .49.

Additional results. A two-tailed t-test conducted on the scaled score means of the 10 procedural items and 10 conceptual items combined showed there was no difference in performance between the comparison and intervention group ($p > .05$). For the procedural items, three out of the top four most difficult items involved the concept of slope and two out of the four most difficult items involved graphing. For the conceptual items, three out of five of the most difficult conceptual items involved explaining concepts from a table, graph, and equation. Of note, the graphing item (16) was also difficult, having a scaled score mean similar to the scaled score mean for the graphing items in the procedural items (.66 vs. .72).

Qualitative Analysis

Categories and student response counts. As explained in the methodology section, the categorization and merging of initial categories of explanation by students on questions 15 and 17 according to their types of reasoning led to four categories of student thinking about linearity. Table 4 shows the counts for student responses in the four categories of student thinking about linearity on items 15 and 17 of the unit assessment. There were a total of 31 responses from the comparison group and 35 responses from the intervention group (out of 71 participants) on item 15, and a total of 31 responses from the comparison group and 36 responses from the intervention group (out of 71 participants) on item 17 (one student in the intervention group did not respond to item 15 but did respond to item 17).

Student response counts summary and analysis. Seven of the 31 responses (23%) in the comparison group and 14 of the 35 responses (40%) in the intervention group on item 15 were placed in the covariation reasoning category (e.g., "It is linear b/c for every gallon added the seconds go up by 3, the rate is always the same"). A comparison of

Table 3
Distribution of Scaled Score Means of Conceptual Items 11, 17, and 20

	Item 11		Item 17		Item 20	
Scaled Score Measure	Comparison ($n = 34$)	Intervention ($n = 37$)	Comparison ($n = 34$)	Intervention ($n = 37$)	Comparison ($n = 34$)	Intervention ($n = 37$)
Minimum	0	0	0	0	0	0
Quartile 1	.33	.66	.25	.25	0	.25
Median	.33	1	.25	.5	.25	.75
Quartile 3	.67	1	.5	1	.25	1
Maximum	1	1	1	1	.75	1

Table 4
Qualitative Analysis Category Student Response Counts

	Item 15		Item 17	
Qualitative Analysis Category	Comparison	Intervention	Comparison	Intervention
Covariation Reasoning	7	16	5	11
Correspondence Reasoning	2	1	2	0
Beginning Quantitative Reasoning	15	12	18	22
Nonquantitative reasoning	7	7	6	3
Totals	31	36*	31	36

*There were 35 student responses, with one response coded in two categories.

proportions test showed this difference was not statistically significant ($p = .1324$). Five of the 31 responses (16%) in the comparison group and 11 of the 36 responses (31%) in the intervention group on item 17 were placed in the covariation reasoning category. A comparison of proportions test showed this was not statistically significant ($p = .1704$).

Two of the 31 responses in the comparison group and one of the 35 responses in the intervention group on item 15 were placed in the correspondence reasoning category (e.g., "The table shows this because no matter what you plug in for s, g will always be 1/3 of that"). A comparison of proportions test showed this was not statistically significant ($p = .4874$). Two of the 31 responses in the comparison group and none of the 36 responses in the intervention group on item 17 were placed in the correspondence reasoning category. A comparison of proportions test showed this was not statistically significant ($p = .1246$).

Although the student responses to items 15 and 17 that were placed in the correspondence reasoning category did not have the correct equation for the situation, there were five comparison students and four intervention students who wrote the correct equation for the situation on item 18 of the unit assessment. This item asked students to write an equation that modeled the situation. However, overall performance on item 18 was poor with the comparison group having a scaled score mean of .48 and the intervention group having a scaled score mean of .64.

The poor performance by students on item 18 may have been related to performance on item 12. This item asked students to identify variable quantities in the situation. The quantitative analysis on this item showed that students had difficulty identifying the variable quantities (scaled score mean was .43 for the comparison group and .54 for the intervention group). An interesting theme observed in the qualitative analysis is a number of students identified a rate as a varying quantity. Ten of the 31 responses in the comparison group and 22 of the 36 in the intervention group claimed that a rate is a varying quantity. This apparent confusion about the varying quantities may have led to difficulty in using the correct varying quantities and fixed quantities when constructing a linear equation for the situation (item 18).

Discussion

One purpose of this study was to explore the relationship between conceptual knowledge and procedural knowledge in the teaching of linear equations in two variables to community college students. The study compared the performance of a group of community college students instructed with a quantitative reasoning emphasis (ending with one day of procedural instruction) to the performance of a group of community college students instructed entirely with a procedural skill emphasis on the same unit assessment. The results of the analysis showed that there was no statistical difference in the performance of the groups on the procedural problems but that the intervention group had a greater performance on the conceptual problems. This supports two claims.

First, a quantitative reasoning emphasis with community college students followed by a short procedural skill instruction can result in greater conceptual understanding while also maintaining procedural skill proficiency compared to a procedural skill only instructional emphasis. This result is consistent with other research on quantitative reasoning in other learning situations (Carlson et al., 2013; Ellis, 2007a; Lobato & Thanheiser, 2002; Simon & Blume, 1994; Thompson & Thompson, 1992) and recommendations that suggest procedural fluency can be supported through instruction focused on conceptual understanding (Leinwand et al., 2014). Therefore, this exploratory study demonstrates that it is possible to address both conceptual understanding and procedural skill with community college students by focusing on conceptual

understanding and spending minimal time on instructing for procedural skill.

Second, a procedural skill with emphasis only on community college students does not result in greater conceptual understanding (in fact, less conceptual understanding) compared to a conceptual understanding instructional emphasis with minimal procedural instruction. If the traditional procedural approach had conceptual instruction mixed with it or at the end of the procedural instruction the result may have been different.

Another purpose of the study was to examine the effects of a quantitative reasoning approach on community college students' ability to reason abstractly and quantitatively about linear relationships.

The first result of the analysis showed that the intervention group had a larger number of student responses that showed covariation reasoning ability than the comparison group on two of the items (44% vs. 23% on item 15, and 31% vs. 16% on item 17). This is similar to Ellis' results (2007b) which showed that students engaged in quantitative reasoning made a greater number of correct global statements about linearity and a greater number of statements of continuing phenomena involving the covarying nature of the quantities. The second result of the analysis showed that the intervention group had about the same number of student responses that showed correspondence reasoning ability compared to the comparison group on two of the items (2 vs. 1 on item 15, and 2 vs. 0 on item 17). These first two results demonstrate that the quantitative reasoning approach supported students' covariation reasoning ability but seemed to have had limited influence on correspondence reasoning (Jacobson, 2014). Clearly, more work is needed to fully support both groups in their ability to express their reasoning, but this seems especially the case with correspondence reasoning.

The third result of the analysis revealed two misconceptions community college students may develop about linear relationships: the idea that a direct relationship between two quantities implies linearity and the idea that a constant rate (like one gallon every three seconds) is a varying quantity. These challenges associated with teaching and learning quantitative reasoning have been noted in other studies (Dougherty & Zbiek, 2010; Lobato & Thanheiser, 2002; Lobato et al., 2010; Thompson, 1988) and are important considerations for instructors aiming to support the development of students' quantitative reasoning. We discuss each in turn.

When students overgeneralize about mathematical relationships such as thinking that direct relationships are synonymous with linearity, we are forced to step back and reflect on the types of examples and problems students encountered during the unit. The examples and problems the intervention group encountered consisted of many examples and problems that were linear, in multiple representations, but only had one problem on a worksheet that was nonlinear in one representation—a table of values. This lack of exposure to nonlinear situations in multiple representations for the intervention group may have led to an overgeneralization about linearity. Incorporating the use of nonexamples and varied mathematical representations into a quantitative reasoning approach could support students in more deeply understanding linearity (Leinwand et al., 2014).

Recall, 10 of the 31 responses in the comparison group and 22 of the 36 in the intervention group included claims that a constant rate is a varying quantity. Thus, over 60% of the students in the intervention group claimed that a constant rate was a varying quantity, whereas less than 1/3 of the comparison group did so. This points to a potential developmental issue as students encounter fundamental ideas associated with rate that require students to join two varying quantities into a single quantity that does not vary, what is known as a composed unit in the proportional reasoning literature (Lamon, 2012). It has made us wonder if making explicit the meaning of a constant rate in terms of the quantities that are varying caused confusion for many of the students in the intervention group. Also because of the short duration, we suspect the intervention students did not have enough time to develop this particular idea. It seems the comparison group had an advantage here, but perhaps only in the sense that they had not been challenged to unpack their knowledge of rates in advance of the assessment. The development of proportional reasoning is foundational to the study of rate and is known to take considerable time. Weber, Ellis, Kulow, and Ozgur (2014) noted the importance of asking students to "identify particular quantities and how they intend to or imagine measuring those quantities" (p. 26). Incorporating this particular recommendation into a quantitative reasoning approach could support students in identifying the nature of quantities involved.

We can conclude from this study that small changes in instruction focused on conceptual understanding (in this case, conceptual understanding associated with linear relationships) can lead to significant differences in students' ability to demonstrate conceptual understanding compared to a predominately procedural approach. The results indicate that a quantitative reasoning approach shows

promise in helping community college students develop covariation reasoning ability.

Limitations

The instructor who used the quantitative reasoning approach in this study had no prior experience with that instructional approach. A more experienced instructor may have been able to better manage the resistance by the students to the approach and better instruct the students using the approach—resulting in better performance on the unit assessment for the intervention group. It must also be noted that the quantitative reasoning approach was only used for one unit of the course (three 75-minute class periods) and started and ended in the middle of the course. Had the instructional approach been used for the entire duration of the course, the performance by the intervention group on the unit assessment may have been greater. Nevertheless, even with these limitations, more evidence of quantitative reasoning in the student responses of the intervention group was observed.

Implications for Future Study

First, this study demonstrates the need for more teaching experiments that explore teaching mathematics for both conceptual understanding and procedural fluency. The study showed that more time can be spent on instructing for conceptual understanding without sacrificing procedural fluency. But how should the conceptual instruction be conducted, integrated, and assessed in conjunction with procedural instruction and assessment? Second, this study demonstrates the promise of a quantitative reasoning approach and a need to further develop and experiment with this instructional approach. Future experiments using the instructional approach need to rely on nonexamples of mathematical concepts and multiple representations of mathematical concepts to achieve deep understanding. The approach also needs to be improved to help students identify fixed and varying quantities in real-world situations and especially help students recognize that a rate is a fixed quantity. How can instruction help students understand the difference between fixed and varying quantities in a real-world situation and especially understand why a rate (as a composed unit) is a fixed quantity even though it is made by joining two varying quantities? Of course, this must be done with an eye to future mathematical work where rates of change are thought of as varying quantities in the study of calculus.

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Finding Alignment: The Perceptions and Integration of the Next Generation Science Standards Practices by Elementary Teachers

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Preparing elementary-level teachers to teach in alignment with the eight Next Generation Science Standards (NGSS) practices could prove to be a daunting endeavor. However, the process may be catalyzed by leveraging elements of teacher science instruction that inherently attend to the practice standards. In this study, we investigated the science instruction of three grade 3–5 elementary-level teachers. We used observation, interviews, and surveys to determine the level to which the teachers perceived they taught and engaged in teaching science aligned with the eight NGSS practices. We found that the teachers were partially, and intrinsically implementing several of these practices in their instruction, and at the same time could not articulate the eight NGSS practices. Our results suggest there may be ample opportunity to build on the current science instruction of elementary-level teachers to bring their instruction into alignment with the NGSS. We found that teachers' perceive professional development, school culture, and access to additional instructional resources to be essential to their adoption of the NGSS practices.

There is wide acceptance that learners benefit from learning science through hands-on and minds-on experiences afforded by inquiry (National Science Teacher Association [NSTA], 2002). Inquiry-based learning using integrated hands-on and minds-on lessons are an engaging way to support the development of lasting conceptual understanding of science topics (Anderson, 2002; Driscoll, 2005). Unfortunately, many elementary students may be excluded from inquiry science experiences (Blank, 2012) which has prompted reform of K-12 science education.

In the United States, science education reform has been motivated by social and economic determinants (Provasnik et al., 2012). The need for well-qualified science, technology, engineering, and math (STEM) professionals is at an all-time high and is anticipated to continue to increase, A number of efforts have been taken to improve STEM education in the United States, including the development of the NGSS (NGSS Lead States, 2013). A significant aspect of the NGSS is the standards of practice, which if embraced by teachers, would require a more authentic approach to science teaching and learning (Nadelson, Seifert, & Hendricks, 2015).

The importance of the NGSS practices to teaching and learning science and our experience working with preservice and in-service teachers to teach science prompted us to consider how much the current science instructional practices in K–12 are aligned with the NGSS practices. We teach courses within a secondary STEM teacher preparation program, and in the first course, our students spend time in elementary-level classrooms observing the teachers and teaching several STEM-focused lessons. Of particular interest to us was how much the cooperating elementary-level teachers may be naturally or inherently teaching science aligned with the NGSS practices, as this group of teachers is critical to providing their students with the foundation for more advanced science learning. Further, by teaching aligned to the NGSS standards these teachers are modeling progressive science instruction for the student teachers. Our exploratory research is the first we are aware of that has empirically documented the extent to which the NGSS practices might be inherent in the current practices of elementary-level teachers. Thus, our research fills a gap in the literature regarding how elementary-level teachers may be explicitly or implicitly engaging their students in the NGSS practices and the potential affordances and barriers to the teachers' NGSS instruction.

Review of Literature

Science Education Reform

There is a major science education reform effort taking place in the United States with the development and adoption of the NGSS (NGSS Lead States, 2013). There is great expectation that the NGSS will lead to increased interest and performance in science resulting from better instruction by teachers (Harris et al., 2015). However, the expectations and anticipation surrounding science reform is not a new idea. Since Russia's launching of Sputnik in 1957, there have been a number of initiatives that have been adopted and promoted in the United States with the goal of improving science education (Yager, 2000). Many of the reform efforts of the 1950s and 1960s were developed around the assumption that students learn science better when they engage in scientific activities in

ways similar to scientists (Schwab & Brandwein, 1962; Yager, 2000).

Ironically, the mid-century science reform initiatives emphasized the use of textbooks and lectures, which were commonly perceived to be a source of science knowledge that teachers could use to have their students effectively learn science; from content to technique (Yager, 2000). More sweeping changes to science education followed these reform efforts. Supported by the National Research Council's recommendations (National Research Council [NRC], 1996), an inquiry approach or use of investigations in science instruction is now considered to be a more effective and authentic way to engage students in learning science.

Teacher Beliefs

Research supports the conception that self-efficacy influences teachers' science instruction (Guskey, 2002; Lakshmanan, Heath, Perlmutter, & Elder, 2011; Ramey-Gassert, Shroyer, & Staver, 1996). Self-efficacy is defined as "beliefs in one's capabilities to organize and execute the course of action required to produce given attainments" (Bandura, 1997). In other words, self-efficacy is a measure of confidence a teacher has for teaching a particular subject, such as science (Bleicher, 2004) or STEM (Nadelson et al., 2013).

Specifically, elementary-level teachers tend to lack confidence to teach science and therefore may avoid teaching it altogether (Appleton, 2003; Milner, Sondergeld, Demir, Johnson, & Czerniak, 2012). Appleton (2003) reports that elementary teachers tend to have gaps in their content knowledge, which limits their motivation and engagement in teaching science. Appleton also found that those teachers who commonly use hands-on activities for teaching science, borrowed activities that worked from their teaching of other subjects. Thus, there is support for the notion that when teachers engage in science instruction, they tend to draw instructional activities from experience, which may or may not be aligned with the instruction needed to address the practices of the NGSS. Thus, we maintain that there is potential for some of elementary teachers' science experiences to be aligned with elements of the NGSS practices and if these can be identified and supported, they may act as a foundation for their confidence development and sustained change in science instruction.

In their study of teacher beliefs and factors that motivate change in teacher behavior associated with implementing science reform efforts, Haney and Czerniak (1996) found that teachers' attitudes were highly predictive of the teachers' intent to implement the reform. Similarly, Levitt (2002) contends that teachers' science knowledge, their

Next Generation Science Practice Standards

- Practices:
  1. Asking Questions
  2. Developing and Using Models
  3. Planning and Carrying Out Investigations
  4. Analyzing and Interpreting Data
  5. Using Math and Computational Thinking
  6. Constructing Explanations
  7. Engaging in Argument
  8. Obtaining Evaluating, and Communicating Info

Figure 1. The practice of the NGSS.

experience learning science, and application of science knowledge can impact how teachers believe that science should be taught. While many elementary teachers believe that science instruction should be student centered, many lack experience with inquiry-based instruction (Levitt, 2002; Thomson & Gregory, 2013). Thus, when presented with the expectation to teach science using inquiry many elementary teachers may struggle or completely avoid teaching science. In addition to their lack of experience, teachers reported time and science instructional materials as significantly constraining their ability to effectively implement a student centered science curriculum (Thomson & Gregory, 2013). We speculate that when teaching science elementary teachers may compensate and take shortcuts, maintaining a teacher-centered focus and avoiding in-depth student-centered instruction that are most likely to engage learners in the NGSS practices.

Practices of Science

Science education that immerses learners in the authentic practices of scientists is paramount to helping students develop the conceptual knowledge and skills they will need to be successful in their future science studies (Driscoll, 2005). The NGSS promote the practices of science and engineering that are aligned with the practices of these STEM professionals (NGSS Lead States, 2013). There are eight science and engineering practices in the NGSS (see Figure 1). These practices are a major shift from a strong focus on inquiry to a broad perspective of engagement in scientific thought and actions (NGSS Lead States, 2013).

Although teacher professional development may be key to increasing the quality of science education (Sawchuck, 2010), there may be opportunities to leverage existing teacher knowledge and NGSS aligned instruction to ease or scaffold the development of educator capacity to provide practice aligned science learning experiences for students. Finding the teachers' zone of proximal development may

be the key to effectively engaging them in meaningful and productive professional development (Ash & Levitt, 2003). Thus, we maintain that professional development designed to increase teacher implementation of the NGSS practices may be achieved at a faster rate, and with greater success and retention, if the instruction leverages and builds upon the practices that teachers commonly address in their current science teaching. Thus, we determined it was prudent to examine the extent to which elementary teachers may be currently engaging their students in activities that are aligned with the NGSS science and engineering practices.

Reform Efforts and Teachers' Perceptions

Reform efforts have been part of the education system for decades (Schneider, 2011). Publications such as *Rising above the Gathering Storm* (Augustine et al., 2010) have spawned a plethora of current initiatives supporting science education reform. A sense of urgency to increase the number of students pursuing STEM majors in colleges in order to supply the increased demand for STEM positions in industry has fueled programs sponsored by the federal government, corporations, and private interest groups (Obama, 2009).

The NGSS (NGSS Lead States, 2013) are an attempt to reform science and engineering education in K–12 education. Regardless of the merits or structure of educational reform efforts, teacher knowledge and implementation of the policies, standards, and practices is crucial to the success of such initiatives (Darling-Hammond, 1996, 1997, 2000; Darling-Hammond & Sykes, 1999). The likely dichotomy and perhaps discontinuity between the developers and promoters of reform mandates and the educators charged with implementing the initiatives creates a unique challenge for reform success (Craig, 2006). As Craig (2006) reports, teachers tend to focus on the quality of instruction and classroom interactions while reform promoting agencies tend to focus on the logistics of institutional implementation, such as the number of schools involved, stage of implementation, and fidelity of implementation. Unfortunately, many curriculum developers and reform leaders fail to consider the belief systems, culture, and knowledge levels of teachers, resulting in a failure of reform efforts (van Driel, Beijaard, & Verloop, 2001).

We argue that careful consideration and examination of teacher perceptions, knowledge, and practices associated with a reform effort is fundamental to the development of the strategies and support necessary for the successful implementation of a reform initiative. Thus, there is high justification for our research of the knowledge, perceptions, and practices of elementary-level teachers from the perspective of the NGSS standards, particularly to determine areas of extant alignment and misalignment.

Science in the Elementary Classroom

There are multiple influences on elementary teachers' engagement in science instruction (Duschl, Schweingruber, & Shouse, 2007). According to the National Survey of Science and Mathematics Education, only 39% of elementary teachers surveyed felt well prepared to teach science, which contrasts starkly to the 81% of elementary teachers surveyed who felt well prepared to teach language arts, and 77% of elementary teachers surveyed who felt well prepared to teach math (Banilower et al., 2013). When the survey of science teaching was broken down into subject areas, only 29% of those surveyed felt well prepared to teach life science, 26% felt well prepared for earth science, and 17% felt well prepared to teach physical science (Banilower et al., 2013). Engineering, now a focus for the NGSS, only received a high confidence rating of 4% by the teachers participating in the same survey (Banilower et al., 2013). Thus, levels of preparation to teach science and the associated lack of confidence are substantial factors that are likely to influence how elementary teachers engage in science instruction. We argue that the anticipated low level of preparation to teach science and the anticipated lack of authentic science experiences of elementary teachers, there is a high likelihood that elementary-level teachers do not engage in instruction that is aligned with the NGSS practices. Consequently, there is justification for documenting elementary teacher engagement in teaching aligned with the NGSS practices to plan and provide meaning professional development to support their science teaching effectiveness.

Purpose of Study

The overarching goal of our research was to determine the how and why elementary teachers were or were not implementing the NSGG practices as part of their curriculum and instruction. We used the following questions to guide our exploratory investigation:

- What NGSS practices are elementary teachers currently engaging their students in when they teach science?
- What are elementary teachers' perceptions of teaching science and the NGSS?
- How do teachers' beliefs affect their focus on providing instruction aligned to the NGSS practices?

Design and Methodology

Participants and School

For our research project, we visited a K–5 school located in a large suburban area in the Pacific Northwestern United States. The school had recently been designated as a STEM

Table 1
Participant Demographics

Participant	Sex	Years Teaching	Grade Level	Degrees Held
Mr. Richards	M	12	5	B.A./M.A.
Ms. Jones	F	10	4	B.A.
Ms. Baker	F	27	3	B.A./M.A.

academy. The population of the school was approximately 690 students, who were from a range of social economic backgrounds, but tended to be grouped primarily as middle class. Three teachers agreed to participate in our study. The teachers (which we report using pseudonyms—see Table 1) have all taught for 10 years or more. The teachers were distributed across grades three, four, and five. Our participants included one male and two females, all Caucasian.

Data Collection

Teaching observation. We requested that the teachers teach a science lesson using their standard approach. Our goal was to observe and document the approach that the teachers typically use to teach science. We conducted two observations of each of the teachers, using a laptop computer to take extensive and detailed field notes documenting the science instruction. The primary question we expected to answer through observation was: to what extent were the teachers integrating the NGSS practices into their science lessons? Given the exploratory nature of our research, we did not develop an observation protocol but instead documented all science teaching activities through field notes.

Semistructured teacher interview. We arranged to interview the three teachers following the classroom observations. We met privately with each of the teachers in their classrooms. We interviewed Mr. Richards before school and Ms. Jones and Ms. Baker after school. We recorded the interviews using a tablet computer for later transcription. Through the interviews, we were seeking to expose evidence to explain the teachers' approach to their science instruction. To guide our interviews, we asked the participants to respond to a combination of knowledge, pedagogy and professional development prompts. The primary knowledge question we asked the teachers was "Tell me all you know about the Next Generation Science Standards." The pedagogy prompts included, "How do you make science engaging for your students?" and "How do you integrate math into your science lessons?" Our professional development items included, "What kind of professional development for science instruction would be most useful?" and "What obstacles do you feel you have in teaching science?" Although we had created and used the prompts for the interviews, our objective was to create a context for the participants to share their science teaching perspectives and justification for their instructional practices. The interviews had a duration of about 20 to 30 minutes.

Teacher survey. Following the observed science lesson instruction, we asked each teacher to complete a survey, which we used to triangulate our data. The survey consisted of 23 items. The first 18 questions offered response options using a 5-point Likert scale, with "1" being "strongly disagree" and "5" being "strongly agree." The remaining five questions were answered in open response format.

Based on our desire to triangulate the NGSS instructional data, we conducted a follow-up survey of the teachers' NGSS instructional perceptions and activities. We were not able to locate any extant survey tools that explicitly focused on elementary teacher perceptions and engagement in teaching the NGSS practices; therefore, we determined there was a need to develop the tool. The survey we developed included items associated with general knowledge of the NGSS such as, "How familiar are you with the Next Generation Science Standards?" which the participants responded to using a four-point scale from "1," representing "Not at All," to "4," representing "Very Familiar." We also included several items related to pedagogy such as "During science lessons, probing questions are important" and "Students learn science best when they are engaged in hands on experiences," which were responded to on the 5-point Likert scale. Our professional development subscale included items such as, "The teachers at my school receive adequate professional development for science instruction." Given our small sample and the exploratory nature of our research, we intended to analyze the responses using a descriptive approach.

Due to the exploratory nature of our research, we determined that we could use the literature and our years of experience working with preservice and in-service elementary teachers to establish the validity of our survey items. Working together and independently, we examined the items in terms of the constructs we desired to measure and assured they were aligned with the extant research and our research goals. We did make some modifications in the language of some items to increase clarification and alignment with our targeted constructs. We did not have the statistical power to calculate the instrument reliability, and therefore reported our results descriptively.

Our research was authorized by a university institutional review board.

Data Analysis

Coding

Observations. To code our observation data, we created a spreadsheet of the NGSS practices and simplified the descriptors for each of the eight practices to help us quickly determine if a practice was attended to during instruction. We then analyzed the field notes for evidence of teaching to the NGSS practices. If a practice was observed, we coded the observation text with the number associated with the practice. For example, if we documented a teacher having students draw a diagram to better understand a science concept, a process associated with NGSS Practice 2 "Developing and Using Models," we would code the passage in the field notes with a "2." We provided no code for the instances in which we were not able to identify evidence of a specific NGSS practice.

We encountered some complications with our coding, especially involving Practice 3, "Planning and Carrying Out Investigations." The source of the challenge was based on the structure of our field notes; certain aspects of our notes documented teachers talking about activities (NGSS practices) that the students were to engage in, while other dialogues (which were similar in content) documented the student actually conducting an experiment. However, the dialogue for these two different classroom interactions read relatively the same. Thus, we decided that it would be beneficial to create a subcode for NGSS Practice 3 to differentiate the two contexts. In the final coding, we assigned 3-P for situations that were representative of teacher presentation of how to conduct an investigation, and 3-C for the context in which investigations were being conducted by the students.

Interviews. Prior to coding the interview data, we transcribed the recorded dialogue, which allowed us to effectively analyze the data. Again, we were seeking evidence of perceptions, knowledge, and instructional approaches related to the NGSS practices. Therefore, we conducted a content analysis using combination of a priori (deductive) and post hoc (inductive) codings (Miles & Huberman, 1994) in an effort to document expected themes and expose unexpected trends in the data related to science instruction and the NSGG reform initiative.

Survey Analysis

Teacher surveys. We used descriptive analysis to examine the teachers' responses to the surveys. To determine the relative strength of the participant responses we combined values of related items to form a collecting of composite scores. For example, for questions related to pedagogy we compiled the values of the related instructional items to form an average composite score that we then interpreted relative to other subscale values.

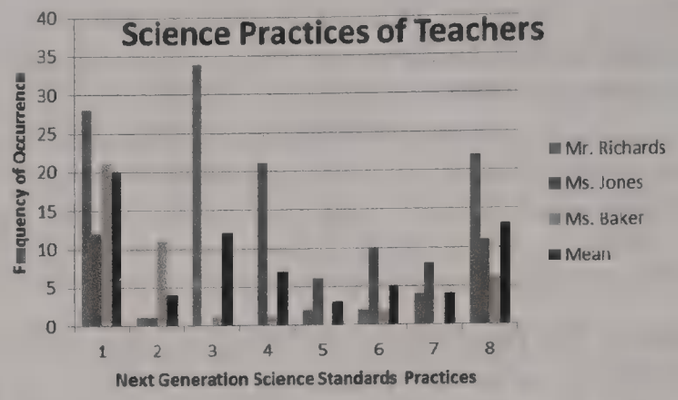

Figure 2. Frequency of science practices used by 3 elementary teachers and overall mean.

Results

Lesson Observation

Our first research question asked, "What NGSS practices are elementary teachers currently engaging their students in when they teach science?" To answer this question, we examined our data for high and low occurrences of observed engagement in the practices. We tallied the number of times each teacher attended to each of the practices in their lessons (see Figure 2). In addition, we examined the teachers as a group, averaging the number of times they engaged in teaching to the practices during the six lessons that we observed (see Figure 2).

For Mr. Richards, we found that he frequently engaged the students in practices 1, 3, and 8 (see Figure 1 for list of the 8 NGSS practices) while engaging the students in Practice 2 and Practice 7 with substantially lower frequency. Both of the science lessons we observed Mr. Richards teaching involved him engaging students in carrying out investigations (doing experiments), hence the high result for Practice 3. These results suggest that Mr. Richards was taking a very hands-on approach to teaching science, but did not appear to be effectively or strategically integrating the more minds-on NGSS practices such as examining data and building meaning.

For Ms. Jones, we found that she engaged her students in practices 1, 2, 4, and 5 with the greatest level of frequency. She also incorporated some of practices 6, 7, and 8. We did not observe Ms. Jones teaching to Practice 3; however, our observation suggests that she engaged her students in Practice 3 the day prior to our observation. One of the lessons we observed Ms. Jones teach involved providing

students with instructions to guide them through graphing results from a deer and wolf simulation they experienced the previous day, resulting in their high use of the NGSS practices of analyzing and interpreting results, using math thinking, developing models, and asking questions.

The lesson observations of Ms. Baker revealed her engaging the students in practices 1, 2, and 8. The practices that Ms. Baker did not attend to in her instruction were 3, 4, 5, 6, and 7. The science lesson we observed in Ms. Baker's class involved students learning about simple machines. Ms. Baker effectively engaged the students in NGSS Practice 2, developing and using models, by having them interpret diagrams depicting simple machines. Ms. Baker gave students the opportunity to create and interact with a dynamic model by having the students roll their pencils down the inclined plane they created with their binders. She prompted the students with many questions throughout the lesson to engage the students in thinking about benefits of the simple machines they were learning about. During the lesson the students kept track of their findings in a science notebook. The approach that Ms. Baker used to teach simple machines integrated frequent use of NGSS practices 1, 2, and 8.

We examined the engagement in the practices of our three participating teachers as a whole. We averaged the tallied observation for the three teachers and found that in general, the teachers were most likely to include opportunities for students to engage in practices 1, 3, and 8, and were less attentive to practices 2, 4, 5, 6, and 7. Similar to the situation with Mr. Richards, we interpret this finding to indicate that the teachers tend to engage their students in hands-on activities and are less likely to engage their students in the minds-on aspects of the practices such as interpreting data and arguing from evidence.

Teacher Interviews

Our next two research questions asked, "What are elementary teachers' perceptions of teaching science and the NGSS?" and "How do teachers' beliefs affect their focus on providing instruction aligned to the NGSS practices?" To answer these questions, we analyzed the interview and survey responses of the participating teachers. We coded the interviews for knowledge of NGSS, professional development, and obstacles, which we aligned with our interview questions. We also developed and used the emergent codes for beliefs and priorities. We present our codes, representative participant statements, and interpretations of the statements in Table 2. We generated the interpretations using the context of the elementary teachers teaching science aligned with the NGSS practices. The interpretations are a reflection of our codings and provide potential explanation and justification for the teachers' statements.

Our analysis of the participant interviews revealed a diversity of potential barriers to implementing the NGSS practices. Our analysis also illustrates how teachers' beliefs impact practice. For Mr. Richards, the fact that he valued constructivism explained his frequent use of hands-on lessons during our observations. Similarly, the fact that Ms. Baker does not believe her young students are ready to integrate math into science sheds light on why she had limited use of Practice 4 or 5 in her science lessons. The variety of factors impacting teacher practice and engagement in teaching to the NGSS standards was revealed throughout the interviews, from individual issues of preparation, to systemic issues of cultural focus and organizational priorities. Thus, there may be issues that teachers may be able to address directly (e.g., professional development) or may have limited influence (e.g., shift in school or district support for the NGSS). It is important to note that our three participants taught in the same school, and yet shared a wide diversity of responses and had little overlap.

Surveys

To further triangulate the teachers' perceptions and beliefs about teaching and learning associated with the NGSS, we examined their responses to the survey. Again, our survey contained a combination of selected and free response items. Thus, our analysis involved organizing a combination of recorded values (for selected response items) and coding responses (for the free response items).

Selected response items. Our analysis of the selected response items revealed some response consistency, particularly items 8, 9, 11, 12, and 13, which were related to instruction (see Table 3). Some items included responses that were somewhat aligned, such as items 1 and 4, which were related to the priority and support of teaching science. We also found items 2, 3, 15, and 16 to have a diversity of responses, items that related to support and engagement in science teaching. Thus, we found consistency in thoughts about instruction, somewhat aligned perspectives of priority and support for teaching science, and divergent views of support and engagement in science curriculum (see Table 3). The participants' responses to the selected response items corroborated the data we gathered through the interviews, indicating that the participants were consistent in their perceptions and engagement in teaching science and the NGSS standards. For example, the teachers all strongly agreed that they enjoyed teaching science, which they also shared in the interview and was apparent in our observations. Similarly, the teachers shared a diversity of

Table 2
Codes, Representative Participant Statements, and Interpretations

Code	Representative Statements	Interpretation
Knowledge of the NGSS Standards Subcodes: Standards, Practices, Access, Detailed Explanations	"It looks like all common cores, there's higher standards." (Mr. R.) "Every once in a while they appear on the website and then they are gone for a while." (Ms. J.) "I couldn't tell you how they differ from what we're already using." (Ms. B.)	▪ Limited knowledge ▪ Limited interaction ▪ Limited exposure ▪ Limited access
Teacher Beliefs Subcodes: Student expectations, Curriculum Integration, Student Centered, Teacher Classroom Control	"As far as their math skills, they are still making these jumps from being very concrete. . .to ask them to use math tools in a science lesson is asking too much." (Ms. B.) "My philosophy on all education is constructive based, that they have to construct the meaning themselves." (Mr. R.) "I think math and science is together, I don't think there is a separation." (Mr. R.)	▪ Limited expectations for student learning ▪ Integrating STEM
Priorities Subcodes: Standards, Content, Classroom, School, Community, Students	"Obviously teachers are focused on Common Core – math and English language arts." (Mr. R.) "I'm working with the committee to try to get the whole school that way [as a STEM academy] but that's a challenge in itself." (Ms. J.)	▪ Focus on Common Core ▪ Shifting school mission and culture
Obstacles Subcodes: Equipment, Administrative Support, Culture, Norms, Knowledge, Time	"We're asked to do more and more without much time and to scramble to get kit pieces that work." (Ms. J.) ". . . but we don't have the stuff to do that." (Ms. B.) "My teaching approach is the cafeteria plan and I get a little bit for language arts and I get a little bit for math and we hope it all comes out to something meaningful in the end." (Ms. B)	▪ Misalignment with the school culture ▪ Lack of instructional materials ▪ Lack of time ▪ Lack of knowledge
Professional Development Subcodes: Relevance, Access, Engagement, Needs	"I did not do the PD last summer because I did not get the courses I wanted. The problem is that they don't rotate new things [course offerings] in." (Mr. R.) "The local PD is fabulous but it is very limited." (Ms. J.)	▪ Misalignment between needs and PD offerings ▪ Lack of a range of PD opportunities

views about having enough time to teach science which is consistent with how much time they indicated they spent teaching and the way that they seemed to structure their lessons as being more student centered rather than teacher centered.

Free response items. In addition to the scaled answers, the teachers were also asked questions requiring a written response. These responses also further support the analysis of the interviews. When asked, "Approximately how much time do you spend teaching science each week?" teachers responded with 2–3 hours, 2 hours, and 1.5 hours, respectively. The average of about 120 minutes a week is consistent with national average (Banilower et al., 2013). When asked "What kind of science supplies would you like to have in order to become a more effective science teacher?" Ms. Baker responded with, "The textbooks we have don't adequately cover our grade-level science units," indicating a reliance on printed instructional materials. In response to the same question, Ms. Jones responded, "Engineering supplies and mini units of things to teach our concepts to a fuller depth than the bare minimum kits we have," indicating a focus on instructional tools and items, particularly for doing the process of science.

The responses to our item asking the teachers to describe their science teaching strategies indicated our participants were focused on hands-on and inquiry lessons. Mr. Richards responded to the prompt with, "Inquiry based STEM lessons." His response aligned with the interview responses where he indicated his strong constructivist beliefs, as well as his opinions on the importance of integrating math with science. Again, they are strongly focused on NGSS Practice 3. Ms. Jones responded to the same item with "hands-on, scientific process, sorting, organizing, building, constructing, reading, writing." Ms. Jones's response indicates that she is an advocate for integrating science with other subjects, and alignment with a broader range of NGSS practices. Ms. Baker's response to the strategies she used were diverse as she reported, "Investigation experiences. . .practicing steps of the scientific method. . .video clips from Bill Nye and

Table 3

Participants Responses to the Survey Selected Response Items (Items Were Answered on a Five-Point Likert Scale Ranging from Strongly Disagree to Strongly Agree)

Question/Statement (Construct)	Mr. R.	Ms. J.	Ms. B.
1. Science is an important part of the curriculum. (Support for teaching)	SA	SA	A
2. I had adequate training to teach science in my teacher preparation program. (Engaging in teaching)	SA	D	A
3. The teachers at my school receive adequate PD for science instruction. (Engaging in teaching)	A	D	A
4. The culture at my school supports science instruction. (Support for teaching)	SA	A	A
5. I have adequate materials to tech science effectively. (Support for teaching)	N	D	N
6. Students learn science concepts best when they are engaged in hands-on experiences. (Instruction)	SA	A	SA
7. I have enough time to teach science throughout the week. (Engaging in teaching)	SD	N	A
8. I place a high priority on teaching science on a regular basis. (Instruction)	A	A	A
9. I give my students frequent opportunities to collect and analyze data during science. (Instruction)	A	A	A
10. Students are given frequent opportunities to explore science questions in my class. (Engaging in teaching)	A	D	A
11. During science instruction asking probing questions is important. (Instruction)	SA	SA	SA
12. Using models such as diagrams or replicas is an effective practice in science ed. (Instruction)	A	A	A
13. I enjoy teaching science. (Instruction)	SA	SA	SA
14. I have some anxiety when teaching science. (Engaging in teaching)	SD	D	D
15. I enjoyed science when I was a K–12 student. (Engaging in teaching)	A	D	A
16. During my own K–12 science I was given many opportunities to do hands-on science. (Support for teaching)	D	D	A
17. I wish I had more time to teach science each week. (Engaging in teaching)	SA	A	A

University of Mexico which have some creative and engaging ways to drive home the concepts... Demonstrations-teacher led and student led... Group and partner discussion... Observations and analysis... Student projects..." Ms. Baker's response indicates that her science instruction may also be more closely aligned with a greater diversity of NGSS practices, but also retained a focus on traditional approaches to teaching science.

Discussion and Implications

In our research, we set out to determine the extent to which teachers were teaching science in ways that were aligned to the NGSS standards. We also sought to determine the depth of their knowledge of the NGSS and their perceptions about teaching science in general. The premise for our research was the possible current alignment between teacher practice and the expectations of the NSGG standards.

Our research indicates attention toward and support for science education by our participating elementary teachers was constrained, which is consistent with national trends (Banilower et al., 2013). In addition to the standard barrier of prioritizing curriculum that aligns with student performance on high stakes testing, (Banilower et al., 2013), we found that the teachers lacked professional development, a culture of support for science education, and instructional resources. However, we also found that the teachers were instinctively attending to some elements of the NGSS standards, which suggests that with some support and effective models of NGSS aligned curriculum and instruction that the teachers may readily be prepared to align their instruction with the NGSS practices, particularly if we work within their zone of proximal development (Ash & Levitt, 2003). Further, the teachers' engagement in some practices more than others, suggests that they could benefit from professional development tailored to address the practices that were not part of their instruction. How teachers acquire knowledge and embrace instruction of the NGSS practices is an excellent direction for future research.

Our study supports abundant research that teacher beliefs do indeed impact teacher instructional and curricular choices—particularly the and adoption of educational reform initiatives (e.g., Haney & Czerniak, 1996; Levitt, 2002). The interviews and follow-up survey revealed that a myriad of issues was at play with respect to teacher engagement in teaching science and specifically integrating opportunities for their students to engage in the NGSS practices into their instruction. Through our study, we have confirmed that teacher familiarity with the NGSS and their associated practices is limited at best. Thus, preparing teachers to teach to the NGSS practices will likely involve shifts in culture, priorities, knowledge, and allocation of resources. Given the historical limitation of elementary

teacher knowledge in science (Duschl et al., 2007) and the even more constrained knowledge of engineering (Nadelson, Callahan, Pyke, & Schrader, 2009), the K–5 implementation of the NGSS standards will take a substantial investment and will be a long-term process. Further, teachers may need to engage in situations of deep reflection on their practice to gain insight into what elements or aspects of science education they will need to shift and pay attention toward as they consider their instruction and curricular choices and implementation.

In the future, we hope to build on prior research (e.g., Lakshmanan et al., 2011) and investigate the impact that quality professional development can have on elementary teachers' science teaching practices and beliefs. We would like to determine if teacher involvement in intensive NGSS focused professional development revolving around the recommended practices, will result in changes to their practices. Also, we know from our research professional development would need to address teacher beliefs about teaching science aligned with the NGSS.

Limitations

The first limitation of our study is our observation of just two lessons for each of the teachers and the nature of our other data collection. More observations may have provided a more comprehensive view of teacher practices. Also, different phrasing of the interview questions may have led the teachers to respond differently. However, the subsequent conversations and surveys confirmed what we observed suggesting that additional observations were likely to provide similar data.

The second limitation of our study to consider is the nature of our sampling—our participants all volunteered to participate in our research. As made evident from our survey, all three teachers enjoy teaching science and were confident in teaching science. Thus, our study may overestimate the science practices occurring in typical elementary classrooms, and underestimate the level of professional development needed to prepare elementary teachers to teach science aligned with the NGSS standards. Examination of the NGSS practices aligned science instruction of a greater diversity of teachers is an excellent direction for future research.

Conclusion

The NGSS call for teachers to embrace a major shift in their practices to provide opportunities for their students to engage in the practices of professional scientists. Elementary teachers may be particularly challenged as their preparation and experience with teaching science is typically very limited. However, there may be elements of elementary-level teachers' current instructional and curriculum choices that could be leveraged to expand their knowledge and align their teaching with the NGSS practices. Our research provided insight into how elementary teachers may be innately providing instruction and curriculum aligned with the NGSS, and some empirical foundations for directions for professional development.

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Authors' Note

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Toward Meaningful Interdisciplinary Education: High School Teachers' Views of Mathematics and Science Integration

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Numerous national initiatives call for interdisciplinary mathematics and science education, but few empirical studies have examined practical considerations for integrated instruction in high school settings. The purpose of this qualitative study was twofold. First, the study sought to describe how and to what extent teachers integrate mathematics and science curricula in their classrooms after having participated in an intervention to promote and support mathematics and science integration. Second, the study was intended to expand our understanding of the barriers to and factors that enable integrated approaches in high school classrooms. The theoretical component of this study builds on and adapts previous models of science and mathematics integration to introduce the Intradisciplinary, Cross-disciplinary, Mutlidisciplinary, Interdisciplinary (ICMI) framework for identifying and defining classroom integration strategies. Findings include a description of several distinct practices high school teachers related to integrated instruction as well as the trade-offs teachers considered when making decisions related to integrated curricula. The implications of the findings for researchers and practitioners are discussed. Finally, we propose the conceptualization of "interdisciplinary pedagogical content knowledge" in mathematics and science as an area of focus that will enable teachers to successfully move toward interdisciplinary instruction.

Key indicators of student achievement at the national and international levels continue to illuminate the need for the U.S. educational systems to improve, and shortcomings in students' achievement in the areas of mathematics and science have been exposed. Perhaps most disturbing is the pervasive belief that America's public schools are not adequately motivating or preparing students to participate in pursuits related to science, technology, engineering, and mathematics (STEM). A broad examination of trends in mathematics and science education reveals numerous calls for interdisciplinary mathematics and science in classrooms as a potential means to increase engagement (Schroeder, Scott, Tolson, Huang, & Lee, 2007). Special attention to curriculum integration can be seen in the national Common Core State Standards Initiative (2010), the Next Generation Science Standards (NGSS Lead States, 2013), and the Partnership for 21st Century Skills. Where integration of math and science has failed in the past, the adoption of these new sets of standards is expected to provide an incentive to teachers through clearer connections between the disciplines (Czerniak & Johnson, 2014).

The scarcity of empirical research that explores, investigates, and articulates the practical integration of science and math in secondary classrooms is perplexing (Berlin & White, 2010; Czerniak & Johnson, 2014; Frykholm & Glasson, 2005). While many posit that an integrated curriculum might allow teachers to more efficiently address standards across the disciplines (Drake & Burns, 2004; Griffiths & Cahill, 2009), others argue that these assertions are based on limited evidence (Czerniak & Johnson, 2014; St. Clair & Hough, 1992). Furthermore, several challenges teachers face when attempting to implement integrated instruction do not appear to have been addressed (Frykholm & Glasson, 2005; Mason, 1996; McBride & Silverman, 1991).

At the heart of the debates around both research and implementation of interdisciplinary models in secondary schools is need for common understandings of the characterizations of interdisciplinary STEM instruction (Stinson, Harkness, Meyer, Stallworth, 2009; Wang, Moore, Roehrig, Park, 2011). Czerniak and Johnson (2014) postulate the focus on integration within the NGSS (2013) will promote further discussion between researchers and practitioners around the definition and forms of integration that could result in more common understandings. Given the complexity around the process of integration and the lack of a common definition, Czerniak and Johnson (2014) argue for the further description of different forms of integration.

Numerous models for math and science integration exist. For example, a large body of literature exists on one potential form of integration, problem-based learning (PBL; Savery & Duffy, 1995). Even with specific approaches for interdisciplinary teaching, such as PBL, efforts to encourage interdisciplinary instruction have been met with limited success. Four primary factors have been seen to

contribute to this. First, secondary teachers see themselves as experts in their own content, but often believe they lack expertise in other disciplines (Berlin, 1994; Pang & Good, 2000; Venville, Wallace, Rennie, & Malone, 2002). Second, the time involved in the preparation of interdisciplinary lessons can be daunting (Clark & Ernst, 2006; Panaritis, 1995; Shoff, 2003). Third, teachers feel they do not have access to appropriate curricular resources (Czerniak, Weber, Sandmann, & Ahern, 1999; Shoff, 2003). The fourth factor that contributes to the limited success of interdisciplinary efforts is the traditional discipline-specific organization of curricula and scheduling (Jacobs, 1989; Morrison & McDuffie, 2009; Venville, Wallace, Rennie, & Malone, 1998).

The Bio-Math Connection (BMC) study addressed all four of the aforementioned obstacles with its interdisciplinary PBL modules designed to connect the math and biology in high schools. Participating teachers participated in content-focused professional development that included background on the biology and math topics integrated in the modules. Our research focuses on the practices of teachers related to integrated instruction as well as the perceived barriers and enabling factors that influence curricular decisions. The purpose of this study was to add to the limited body of empirical evidence on how teachers currently integrate math and science in secondary classrooms by: (a) describing how and to what extent teachers integrate math and science after having participated in PD and used integrated modules, (b) expanding our understanding of why teachers do and do not integrate math and science, and (c) determining if practical, rather than theoretical, math and science integration fits within a comprehensive model that includes nuanced typologies rather than singular conceptualizations of integrated teaching and learning. Specifically, the study was guided by three research questions:

1. How do teachers integrate math and science curricula (e.g., models and instructional approaches to integration)?
2. What do teachers identify as the major enabling factors and barriers in ongoing math and science curriculum integration in high school classrooms?
3. How does a multifaceted intervention with interdisciplinary modules, training and support contribute to the level of teacher interdisciplinary curriculum integration?

A Framework for Integrated Instruction

Many models of integration are presented in the literature (e.g., Fogarty, 1991; Huntly, 1998; Hurley, 2001; Lonning & DeFranco, 1997), primarily focused on the extent to which the disciplines are integrated and the process for doing so. These models do little to inform studies such as this. First, terms used within some models are ill defined. Second, consistent terminology and definitions are not employed across the models. Third, the models are intended to describe different aspects of integration, which makes it challenging to decide how the models map onto one another. Finally, the models do not address how teachers do or do not work together to integrate math and science.

In our study, the intent of the intervention was to promote what is often called interdisciplinary instruction while building collaborations between math and science teachers. Stember (1991) presents a framework for distinguishing between five different levels of "enterprise within and across disciplines" (p. 5). We center our study on the first four of these typologies: intradisciplinary, cross-disciplinary, multidisciplinary, and interdisciplinary. These typologies are derived from two parts: the prefix and the term disciplinary. Taken literally, the word *disciplinary* is defined as "of or relating to a particular field of study" (*Merriam-Webster's*, 2011). The prefix *intra* means "within" a single discipline while *cross* implies going "across" more than one discipline (*Merriam-Webster's*, 2011). Stember (1991) describes *cross-disciplinary* as "the viewing of one discipline from the perspective of another" (p. 4). *Multi* brings in "more than one or two" in the definition (*Merriam-Webster's*, 2011), and Stember distinguishes this from cross-disciplinary through a team approach where each team member offers the different perspective. Finally, *interdisciplinary* implies a connection such as "between, among, in the midst, and reciprocal" (*Merriam-Webster's*, 2011). As Repko (2008) notes, interdisciplinary can be viewed as "between two or more fields of study." This definition implies integration and synthesis of the knowledge and approaches from different disciplines in order to address a problem or issue (Stember, 1991).

Although this framework was proposed to advance the social sciences through interdisciplinary research, we assert that it can be used to describe K–12 instructional approaches. For example, the traditional siloed educational structures are intradisciplinary, as there is no focus on teaching beyond a specific content area in each class. Cross-disciplinary instruction might be seen when a teacher offers real-world examples that draw from other disciplines to offer context for a particular content topic. A thematic unit (Barton & Smith, 2000; Vars, 1991) without an underlying problem or issue would be considered multidisciplinary. The same thematic unit presented with a problem would be considered interdisciplinary regardless of

the teaching by a single or multiple teachers, because the instruction draws on the multiple approaches to address the issue. In K–12 education, the approaches that most closely embody interdisciplinary instruction as defined in this framework are the problem- (Savery & Duffy, 1995) or project-based models (Blumenfeld et al., 1991). In this paper, we will refer to our adapted model as the Intradisciplinary, Cross-disciplinary, Multidisciplinary, Interdisciplinary (ICMI) framework.

Methods

Intervention

The BMC study produced 15 instructional modules designed for interdisciplinary biology-math education in high school. Each BMC module was codesigned by a different interdisciplinary team of experts. Teams of three to four module authors included (1) a mathematician, (2) a biologist, (3) a curriculum development expert, and (4) a high school teacher. In some instances, a single faculty member provided both the mathematics and biology expertise. Comprehensive BMC modules each consisted of 4–6 units, and units included activities and materials for both teachers and students. Each module was intended to be taught over one to two weeks, and both teacher and student versions of the materials were developed.

BMC hosted three-day training sessions for high school biology and mathematics teachers in which they were introduced to the topics and materials, and also had an opportunity to interact with scientists, mathematicians, and one another. Module developers offered short sessions to reinforce the mathematics and biology content that was the focus of each module. For example, one mathematician described her ongoing research on ticks that was the central topic for one module. Then, teachers were introduced to the major elements of the module. Teachers attended in school-based teams of two: one biology and one math teacher. BMC modules were used in diverse high school math and biology classrooms across the country. In all, 62 biology and math teachers in 23 states used the modules as part of the BMC study (Weinberg & Albright, 2011). Of these teachers, 9 teams volunteered to participate in this study, for a total of 18 teachers. Each team was from a different state, including Virginia, Delaware, Pennsylvania, Montana, Massachusetts, Michigan, Oklahoma, Illinois, and Georgia. Although all participant science teachers were teachers of biology, we chose to use the broader term "science" to reduce the risk of overlooking integration that occurred not specifically related to biology.

Data Collection

We adapted the Levels of Use (LoU)-Branching Interview protocol model to both align with the structure of the curricular intervention and expand our understanding about the extent to which teachers employed interdisciplinary practices. The LoU dimension offers a way to help understand the behavioral, knowledge, and skill patterns of teachers with respect to change and implementation of an innovation (Hall & Hord, 2006). The LoU Branching Interview format (Loucks, Newlove, & Hall, 1975) was the foundation for our semistructured interview protocol. The protocol included questions about whether teachers used integrated math and science instruction, the extent to which they made changes, if and how they coordinated or collaborated with other teachers, and their future plans. Before beginning the semistructured interview, we asked questions designed to put the innovation in context including the alignment of an interdisciplinary approach to math and science education with the current goals of the school and the department. For example, we included questions related to administrator and collegial support for new innovations as well as the communication within and between departments. These contextual questions permitted us to gain a deeper understanding of the influence of participation in the interdisciplinary project as well as allow for the identification of enabling factors and barriers related to the ongoing integration of science and math curricula in high school classrooms (Research Question 2). Next, we used the semi-structured interview protocol relative to instruction while using the modules (Research Question 3). Finally, we followed the same protocol, focusing this time more broadly on integrated instruction outside the use of the modules (Research Question 1). Although we used the LoU Branching Interview as a basis for our semistructured interview, we did not assign quantitative LoU levels to participants.

The adaptation process included validation and pilot testing of the LoU protocol. Specifically, a team of faculty who had been trained and certified, and who had used the LoU-branching protocol reviewed the adapted protocol to ensure its strength, credibility, and dependability. After this review, we pilot-tested the LoU with seven teachers before the adapted protocol was used to conduct one-time 45-minute phone interviews with 18 participant biology and math teachers. Prolonged engagement with the teachers throughout a summer professional development workshop and the school year allowed us to establish the rapport necessary to conduct these interviews over the phone rather than in person.

Data Analysis

We used an inductive thematic analysis approach to extract emergent themes related to common responses across all teachers. "Thematic analysis is a method for identifying, analysing, and reporting patterns (themes) within data" (Braun & Clarke, 2006, p. 79). Codes were inductively identified and then categorized into themes and subthemes. The two researchers engaged in this process together in the same room over a four-day period to discuss and come to consensus on the interpretations of the data relative to codes and themes. This consensus process takes into account multiple perspectives and allows for discussion of the themes with direct access to the interview data, which can improve the quality of decisions made about themes (Hill et al., 2005). This thematic analysis enabled us to provide context as well as begin to understand how teachers integrate math and science. It also allowed us to describe the enabling factors as well as barriers to ongoing integration of science and math content. In this way, we were able to identify other influences (outside the scope of the intervention) affecting their decisions about how and if they integrate math and science.

Findings

We examined themes related to each of our three research questions. In this section, we provide those themes and illustrative quotes for each. Where further clarification concerning the interaction between math and science content and/or teacher collaboration was needed, we drew on Stember's (1991) disciplinarity typology. Throughout this section, we refer to teachers through the use of pseudonyms for confidentiality.

Teachers Integrating Math and Science Curricula

Math teachers spoke almost exclusively about cross-disciplinary instruction, as reflected in their use of the term "application" as it related to math content. This focus on the content addressed in the course and how it can be applied in different settings was not present in the responses of science teachers. Mr. Henderson, a math teacher, explained, "The students need to know what they use the algebra for, and that's a prime consideration for us—the areas of application and how [the textbooks] present that to students." Mrs. Parker hoped for more applications for her math teaching, "...that would be the ultimate goal ... for every topic I teach I have at least one application for the kids to experience." Mr. Paige explained that "[the application] gives a use for the skills that we did." Mrs. Elliot expressed concern in her own ability to incorporate applications: "I think applications are something I am very weak on...since I didn't study [applied math] myself, it's hard for me to actually demonstrate how it could be applied..." These applications were typically short in duration and were described as being exclusively focused on the math content. No attempt was made to introduce or reinforce science content. Rather they were used to provide context or relevance for math instead of prolonged engagement with a problem to be solved via math/science.

Science teachers occasionally described lessons or units where students used a combination of science and math to solve a problem. Mr. Collins, for example, taught an interdisciplinary unit on energy in an environmental science class in which students use dimensional analysis to examine energy efficiency in coal-burning power facilities. In another example, an advanced biology class was enhanced with the incorporation of statistics. Mr. Collins and Mr. West described the introduction of statistics into a project focused on plant growth, "It became very clear to the students, 'Holy cow! If you...took the average to make the conclusion, you don't really know whether your treatment had an effect.' Then they could run a *t*-test, and they could say their overall results gave a *p*-value of .03. And then all of a sudden, they realize that's a better way to address the question."

Mrs. Parker's description of integration was the closest to interdisciplinary instruction of any of the teachers interviewed: "As a mathematician our goal is to try to find a pattern and then put in equations with that pattern so that we can predict the future. It's when we can't find a pattern that it becomes very chaotic and we turn to our sciences to look at it deeper so we can find a pattern." Here, she is describing using two disciplines to solve a problem in different ways, which most closely aligns with multidisciplinary instruction.

Evidence of interdisciplinary collaborations among teachers and students was rare, but did exist. For example, one school required that students design and conduct research projects under the supervision of teacher-mentors. Most of these research projects included a combination of science data collection and math modeling. Another example of teacher-student collaboration occurred when Mr. Dabney and Mrs. Bishop combined two of their classes and cotaught a problem-based unit that integrated biology and math content. Based on student interest in the module topic, teachers and students codesigned a place-based research project that drew from topics in their math and biology classes.

Enabling Factors and Barriers to Math and Science Integration

Although we approached this study and the analyses assuming enabling factors and barriers were dichotomous and distinct, it became apparent that this assumption was

overly simplistic. The interrelated nature of the enabling factors and barriers to math and science integration meant that there were common themes that required the researchers to reconceptualize how findings are discussed. Rather than attempting to disentangle enabling factors and barriers to math and science integration, themes are presented here in the way participant teachers talked about barriers and enabling factors—as trade-offs. No single teacher described his or her instruction as fully interdisciplinary. They each described making a complex series of trade-offs that allowed them to teach along the multidisciplinary and interdisciplinary spectrum.

Trade-off #1: Standards. State and federal standards have become the norm in K–12 education, and broad adoption of curricula within the context of these standards brings a complex set of factors to consider. Not only do these standards differ by state, but they also periodically change. A prominent theme was pressure to cover vast amounts of content as articulated in their state's content standards. A related theme was the concern that teachers were sacrificing quality of content address for quantity. For Mrs. Violet, the perception was that intradisciplinary is always the most efficient approach as they are "racing through to get all the objectives in," even though the desire is there to incorporate innovative and/or interdisciplinary elements. Others prioritized interdisciplinary instruction on a topic-by-topic basis. When considering an interdisciplinary approach, Mr. Dabney expressed that logistically and practically "it is easier to keep track when you artificially separate [math and science]." The implications of not "covering" content can be far reaching. In fact, Mrs. Fletcher shared that her math department used an integrated/ interdisciplinary approach in all math courses, but fairly quickly reverted back to a more traditional intradisciplinary approach. The impetus for this decision occurred when graduates arrived at college and found "there would be some of these basic concepts that they weren't exposed to [in high school] or weren't exposed to for long enough to have the solid foundation they needed" (Mrs. Fletcher).

With standards that vary by state and expectations by state, district, and school-level administrators to cover all content standards, many organizations and publishers tailor their resources and textbooks specifically for individual states. Sometimes this placed limits for the teachers in our study on the use of interdisciplinary resources. For example, one teacher described his geometry textbook, which was tailored to his state's standards, as having "like 900 pages with 12 chapters and we have to get through the whole thing. It's just not feasible to take a week to do a project. . ." (Mr. McKay). In other cases, there may not be a need for the interdisciplinary resources. Mrs. Violet described her school's textbook as encouraging integrated connections, "They're just copied paper with problems on it. . .so explanation in class is never a lecture, it's just question and answer on what the concepts underlying the problems are and how the problems connect to one another."

Trade-off #2: Level of control. A second trade-off is the teacher's level of control related to their own course content and its delivery. Some had virtually no flexibility as decisions were made at the district level. The math department at Mr. Paige's school "has been told exactly what they are going to teach every minute of every day and how they are going to teach it." When decisions were made at the district level, some teachers had opportunities to offer input. In instances such as this, teachers described the need to "get agreement from our teammates to do anything different" (Mr. Collins). Still others were told only that they "need to cover this by the end of the semester" (Mrs. Parker) and daily decisions were up to individual teachers. Opinions about the synchronization or curricular control within a school or district were widely varied. This was alternately conceived as constraining, or as what is best for students. For example, Mrs. Parker noted a high student transfer rate between high schools within the district. Using the same materials lessened the impact of the transfer on student achievement, and she described the district-wide synchronization as a benefit for all students, "so that if they need to talk to other students in other classes they're not in a totally different place."

Trade-off #3: Assessment. A closely related trade-off is related to assessment, which includes state, district, and course-level assessments. Several districts required each course to administer up to six common assessments per year. As with standards, teachers' perceptions of these common assessments varied widely. Some described using data to drive discussions around maximizing student outcomes, thereby encouraging teachers to exchange ideas, approaches, and resources. Others felt data were used in a punitive manner, and perceived that they were the targets of unwanted attention if their students did not score as expected or desired, regardless of the cause. For example, Mr. West noted, "If students perform well, people kind of leave you alone." In other cases, these exams brought high stakes for students. Mrs. Ellis described a new test in her district where students "have to pass the Algebra I test or they don't graduate from high school." This is another example of the complex system within which education occurs. At the teacher level, perceptions of the common assessments and how the data are used might be a function

of factors such as how well their students generally perform on the assessments or messages from administrators. Perceptions ranged from the belief that administrators stifle innovation when they require that teachers "stop teaching the curriculum and start teaching to the test" (Mr. Dabney), to the belief in the importance of student performance on these tests.

Trade-off #4: Fit. For classroom teachers, trade-offs related to the fit of existing materials. Some teachers had access to existing curricula tailored to meet the standards while others experienced the opposite as they pieced together materials to meet specific standards. Teachers wanted prepackaged materials appropriate for students with a range of ability levels, including materials that have multiple reading levels and questions of varying difficulty. Curricula need to be flexible for use with students at different levels and in different courses. Furthermore, teachers expressed that materials must link to content standards, and an explicit description of these links should be included. When materials align with existing standards and curricula, they explained, it is easier to insert them into a class. Short lessons with clearly articulated learning goals that align with content standards are more feasible for teachers to meaningfully use. Mr. Paige explained this: "If I change one day, I have to modify all of the lessons around it to make sure that all the stuff I used to teach is still incorporated plus this new idea or try to look at what I can take out to put in this new idea," and Mrs. Fletcher expressed her frustration with trying to fit in interdisciplinary units when "there are topics that you have to sacrifice in order to [teach interdisciplinary topics]." When resources were succinct and could easily be placed within an existing curriculum, the teachers were more likely to use them.

Another important consideration related to fit is the interdisciplinary approach's alignment with the school's focus, initiatives, or mission. Participants described school-level initiatives or foci that helped advance their efforts to integrate math and science curricula. For example, Mr. Collins described how math and science integration dovetailed with his school's focus on lesson study. He was part of an interdisciplinary lesson study to integrate statistics into an accelerated biology course. He believed that "according to admin, the main focus was lesson study. If you were any member of that team you would say that the main focus was to figure out how to teach stats in an accelerated biology class." Mrs. Campbell's entire school was focused on integrating math with everything they do, as is the case for teachers in at least three additional schools included in this study. Other teachers described a focus on increasing reading proficiency. The incorporation of interdisciplinary or integrated lessons was seen by each of these teachers to advance these various school or district level initiatives.

Trade-off #5: Teacher knowledge, skills, and abilities. Each teacher's level of knowledge, skills, and abilities were one of the most influential areas of consideration. Surprisingly, some teachers expressed concern about their pedagogical content knowledge (PCK) or ability to transfer knowledge within their discipline. For example, one of the more novice teachers noted that he was only just ready "to find different activities that go outside of what we're going to learn in math and how it relates to the next topic" (Mr. McKay). This discomfort was not limited to novice teachers, however, as Mrs. Elliott, a veteran math teacher who studied pure math, described her desire to do more application when she said, "it's hard to even know sometimes where it's applied . . . it's hard for me to actually demonstrate how it could be applied."

It was less surprising that teachers expressed varying levels of comfort with the other discipline. Mr. Dabney embraced the unknown and uncertainty and even saw it as a benefit. He did not feel he needed to know everything about biology, and believed it was a benefit that is summed up by a saying that's posted on his own wall, "'you teach best what you most need to learn'.... A teacher who isn't a continuous learner loses sight I think of what it is to learn and what it is to struggle to learn something." Others, even if they had a strong background in the other discipline, were reluctant to include content from an area outside their own, as was seen Mr. Ellis when stated, "I'm pretty confident in my science ability, but I don't like to look stupid either."

Trade-off #6: Collaboration. In practice, collaborative partnerships can be challenging to establish and maintain. As Mrs. Violet stated, "it's a lot more complicated working as a group. Any time you work as a group it takes 3 times as long...in the long run [collaboration] usually has positive effects." At least one teacher (Mr. McKay) felt the school-level "forced" collaboration was not productive or useful. Shared office space with teachers from varuous disciplines was seen to encourage collaboration, as was the proximity of classrooms to teachers from other disciplines. One teacher-team was at a school with only one math and one science teacher, and another's school was so large the front office was approximately a quarter of a mile from her classroom. Teacher schedules and commitments further complicated collaborations when planning and lunch periods were different and teachers were engaged in after-school activities such as tutoring or coaching.

Those challenges aside, many teachers cited collaborations and partnerships as being imperative when attempting a new classroom innovation, particularly when that innovation included integrating content from another discipline. For some, this type of collaboration was already in place in the form of cross-disciplinary teams. Mrs. Parker said, "I know that there are certain teachers in this school who want to do the same thing in their class that I want to do in mine." Another teacher (Mrs. Ward) lamented the implications of her school's lack of collaboration and communication: "I would say that at this point [collaboration is] sort of shamefully low. We don't even know. . .when we're teaching a math concept that's going to be important two months later in chemistry. And chemistry students struggle with lessons on [significant figures] and the math teachers don't do anything to help that."

Intervention Contributions to Interdisciplinary Instruction

The BMC study included modules as well as additional supports. We found there were lasting and meaningful influences on teachers and therefore their classrooms. The team-based approach of BMC was particularly powerful, as evidence by the teacher team of Mr. Dabney and Mrs. Bishop. Mr Dabney believed that "the value in this for us has been that if I had gone out to these sites alone with my background in math and a little background in science, I guarantee that we wouldn't have come out with what we did." This teacher team advocated for a change in schedule so they could have back-to-back blocks with the same group of students to allow for them to better collaborate on interdisciplinary units with these students and team teach as appropriate. Mrs. Campbell described that it "opened up communication across the disciplines."

As participants worked through the interdisciplinary content of the modules, many were inspired. Mrs. Campbell stated that it "helped my awareness. It's not that I couldn't do it or wasn't open to it, I just don't think I was as aware." Others describe the exposure to models of instruction as meaningful. This was especially the case for Mrs. Ward, who said, "it's hard to ask teachers to teach in a way that they've never been taught. . . and now I know what some of these effective strategies look like."

Discussion

Describing Integrated Math and Science Instruction

One purpose of this study was to describe how teachers integrate math and science curricula in their classrooms. Teachers described integration approaches that were primarily cross-disciplinary but also included descriptions that align with intradisciplinary, multidisciplinary, and interdisciplinary approaches. Notably, when teachers were asked to define or give an example of curriculum integration, there were distinct and consistent differences in how biology and math teachers defined integration. Math teachers referred to taking their math concepts out into the world, and consistently used the term "applications." In contrast, biology teachers described drawing on other disciplines during science instruction that went beyond the use of applications. They described the contributions of math to solve scientific problems. Although both sets of teachers discussed how they applied math to other disciplines, the science teachers' description more closely aligned with interdisciplinary instruction; the mathematics was used to solve and describe scientific phenomena. Math teachers primarily described cross-disciplinary approaches, where the goal was to give examples of the usefulness of specific math content. This variation among teachers' characterizations of interdisciplinary STEM instruction aligns with the multi-categorical typology that served as our theoretical framework, and it also aligns with other studies (Meyer, Stinson, Harkness, Stallworth, 2010; Wang et al., 2011).

Complexities of Implementation

When looking to effect change on a larger scale (e.g., across more districts, to other domains), it is insufficient to examine only short-term measures that do not extend beyond the specifics of interventions and their implementation. This study focuses on teacher use and spread of innovative interdisciplinary teaching practices. Teachers voiced the complexity of integrating math and science in the classroom, and we related that complexity to a series of trade-offs they consider when making decisions on how and with whom integration occurred.

The challenges and factors that allow math and biology teachers to integrate content in their classrooms were fairly consistent across disciplines. Some of these themes parallel findings from earlier studies, and some appear to offer additional understanding of the issues teachers face and the complex systems within which teachers work. One notable parallel is the concern about the sequential nature of math, and the challenge this presents when a school attempts to implement a fully integrated curriculum (Mason, 1996). This was echoed by one teacher who lamented the loss of the interdisciplinary curriculum in her school as a consequence of students performing poorly in college. Another parallel finding is the lack of science materials for use during math instruction (McBride & Silverman, 1991). Themes of collaboration and outside influences on curriculum decisions that emerged mirror those found in

prior research (Basham, Koehler, & Israel, 1994; McGehee, 2001; Meier, Nicol, & Cobbs, 1998; Venville et al., 2002). However, unlike prior studies (e.g., Lehman, 1994) that found a lack of follow-through even with teachers with positive perceptions of integration, the teachers in our study described continued efforts to integrate. Many of them attributed this to the explicit interdisciplinary focus of the BMC modules and the intentional time for teacher collaboration.

Conclusion

We continue to explore the nuances among teacher responses in an attempt to propose potential solutions to these barriers and suggestions for how teachers might be best supported to make meaningful changes in order to integrate math and science. For example, in the beginning of this paper, we introduced four factors that contribute to lack of success of interdisciplinary approaches. We now posit a fifth: interdisciplinary pedagogical content knowledge (IPCK), which is differentiated from interdisciplinary science inquiry PCK (Chowdhary, Liu, Yerrick, Smith, & Grant, 2014), as it is not exclusively focused on inquiry or anchored in a single discipline. Instead, IPCK focuses on (a) subject matter knowledge for teaching where disciplines intersect (e.g., biology and math), and (b) the methods for representing concepts at this intersection in comprehensible ways (Shulman, 1986). Although teachers described varying levels of comfort in their own PCK, almost all teachers expressed some level of discomfort in knowing how to teach interdisciplinary content. It was evident in our interviews that teachers need the interdisciplinary pedagogical skills in addition to the pedagogical content knowledge in their own discipline to successfully move toward interdisciplinary instruction. Supports like BMC that include not only modules, but also content training, modeling of interdisciplinary pedagogy and collaboration, and ongoing supports may make balancing some of these trade-offs less daunting, but more research within the domain of math and science integration is needed.

The findings from this study add to the discussion on the definition of integrated instruction and what this means in practical terms. Lederman and Niess (1997) argue for the importance of labels to describe instructional approaches for integration and the necessity for maintaining disciplinary boundaries. In this study, we began by using the ICMI framework applied to integrated teaching as a theoretical model. In our application of this framework, intradisciplinary instruction represents instruction focused on a single content area without the inclusion of other content areas. Cross-disciplinary and multidisciplinary approaches integrate content from multiple areas; distinguishable disciplinary content still exists. An example of cross-disciplinary instruction would be using science applications to provide context to math content. Multidisciplinary instruction might include discussion of a problem from both a math perspective and a science perspective. Conversely, in interdisciplinary instruction the disciplines are less discernible as instruction begins to move away from discipline-specific approaches toward a more seamless integration of content.

In our study, even though teachers taught with the same set of interdisciplinary BMC modules, their descriptions covered the spectrum from intradisciplinary (e.g., teaching a topic by itself) to cross-disciplinary (e.g., offering applications of one content topic in another context) to multidisciplinary (e.g., offering different perspectives on a single topic). Few descriptions of teachers' instructional approaches align with the definition of interdisciplinary (e.g., solving a problem through a combined set of knowledge and approaches), but all of them described some form of integration they implemented in their classes.

We know that implementation of interdisciplinary lessons is influenced by contextual factors (Pang & Good, 2000). This was echoed by teachers in their varied reasoning for the types of integration they used. All teacher participants' described a series of trade-offs for the instructional choices they made. Understanding these trade-offs is important. Knowledge of factors that enable or are barriers to integration will allow developers of integrated curricula to tailor products to maximize potential for adoption and diffusion. However, given the trade-offs and compelling reasons for each integration approach, we question the feasibility of a fully interdisciplinary curriculum. By naming and defining these other integration approaches, we have begun to answer the call of Czerniak and Johnson (2013), who argued for the development of common understandings around integration.

In 1996, Mason stated, "The concept of curriculum integration possesses considerable face validity and commonsense appeal, but what else supports this practice in schools?" (p. 263). Clearly, this question has not been adequately addressed. With the variety of factors affecting the implementation of integrated instructional practices, overall success in the implementation of an integrated curriculum will require coordinated, systematic change. Diffusion research has shown "a flawed process can doom the diffusion of an otherwise effective innovation" (Ellsworth, 2000, p. 27). More comprehensive frameworks are needed to help practitioners implement integrated

approaches and researchers study the impacts of integration on student outcomes. Until that occurs, we cannot begin to study integration in a robust manner.

Our ICMI framework takes into account the complex landscape in which integrated instruction is implemented. We encourage our research colleagues to apply the framework to further describe teacher practices that align with cross-disciplinary, multidisciplinary, and interdisciplinary instruction and the influences of these practices on student learning. Through this, it is our hope to legitimize these integrated approaches through the provision of robust research evidence and meaningful, practical examples. Curricular materials and professional development programs grounded in future research findings based on the ICMI framework will emerge, and we will begin to see more authentic integrated math and science instruction.

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Parents' Attitudes Toward Mathematics and the Influence on Their Students' Attitudes toward Mathematics: A Quantitative Study

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The purpose of this study was to investigate parents' attitudes toward mathematics, their students' attitude toward mathematics, and the influence of the parents' attitude on the students' attitude toward mathematics. Data analyses revealed statistically significant positive correlations between parents' and students' attitudes toward mathematics. Additionally, parents' mathematics attitude significantly predicted students' attitudes toward mathematics (n=146). By understanding the influence of parents' attitudes on students' attitudes toward mathematics, school efforts can be geared toward fostering favorable attitudes toward mathematics among parents.

Many students lack interest and proficiency in mathematics (Rice, Barth, Guadagno, Smith, & McCallum, 2012). In fact, 64% of eighth graders scored below proficient on the 2013 National Assessment of Educational Progress [NAEP] (NAEP, 2013; President's Council of Advisors on Science and Technology [PCAST], 2010). Research suggests a student's home environment may influence their attitude toward mathematics (Sheldon & Epstein, 2005), and parental involvement can increase student achievement (Areepattamannil et al., 2015; Jacobbe, Ross, & Hensberry, 2012; Kliman, 2006; Lopez & Donovan, 2009). As a result, it is imperative that teachers involve parents in their child's mathematical learning (Bofferding, Kastberg, & Hoffman, 2016). Although some parents do not have the mathematical content knowledge or pedagogical knowledge for teaching, parents feel more competent in their mathematical ability and interact more with their child when teachers reach out to them (Drummond & Stipek, 2004; Jacobbe, et al., 2012).

Parental engagement and support is crucial when students are deciding whether or not to pursue science, technology, engineering, and mathematics (STEM) courses (Rice et al., 2012). Fan & Chen (2001) argue parental aspiration and expectation of their child's achievement has a strong relationship with academic success, which in turn is related to their child's attitude toward the subject. For example, children who have high mathematics achievement generally have parents who support their mathematical ability and success (Fan & Chen, 2001; Henderson, Mapp, & Southwest Educational Development Laboratory [SEDL] National Center for Family and Community Connections with Schools, 2002; Ingram, Wolfe, & Lieberman, 2007; Jeynes, 2003; Kliman, 2006; Peña, 2000; Usher, 2009).

Ingram et al. (2007) claim parents generally get involved with their child in mathematics when they have high self-efficacy toward mathematics themselves and when they feel the school supports their involvement. Consequently, it is important for teachers to provide opportunities for parents to get involved and provide necessary tools for parents to help teach their child(ren) (Drummond & Stipek, 2004; Jacobbe et al. 2012; Sheldon & Epstein, 2005). However, some teachers and schools usually are not aware of ways to involve parents in such learning experiences (Ingram et al., 2007; Sheldon & Epstein, 2005), especially when some parents may have negative attitudes toward mathematics. As one approach, researchers suggest family math nights where parents, teachers, and students participate in fun, engaging mathematical activities together that not only provide education stimulus for students, but also prepare parents to help their children with the material (Grant & Ray, 2015; Ingram et al. 2007; Rice et al., 2012; Sullivan & Hatton, 2011). The purpose of this quantitative study is twofold. First, we examined parents' and students' attitudes toward mathematics, and then we investigated how parents' attitudes influenced their child(ren)'s attitudes toward mathematics.

Attitudes Toward Mathematics

Attitudes, emotions, and beliefs make up the affective domain in mathematics education (McLeod, 1992).

Attitudes involve "positive or negative feelings" (Philipp, 2007) toward an object, place, or thing. Specifically, attitudes refer to "affective responses that involve positive or negative feelings of moderate intensity" (McLeod, 1992, p. 581). In other words, it is an individual's like or dislike toward mathematics (Hannula, 2002). We know attitudes about mathematics develop over time (Ma & Kishor, 1997), and teachers, peers, and parents, as well as the environment can influence a student's attitude. Students' attitudes may also be established from their self-perceived abilities, self-efficacy, or social support from teachers and parents (Akin & Kurbanoglu, 2011; Rice et al., 2012; Rowan-Kenyon, Swan, & Creager, 2012; Stodolsky, Salk, & Glaessner, 1991; Tapia, 1996; Usher, 2009; Wilkins & Ma, 2003).

Wilkins and Ma (2003) claim teachers', peers', and parents' positive support help students develop positive attitudes about the social importance of mathematics. Hon and Yeung (2005) suggest when students are surrounded by positive influences, they will be affected in a positive way. Environmental factors including students' home life and access to instructional materials as well as entertainment measures can all have an effect on attitude and achievement (Ames, 1992).

Parents' Attitudes Toward Mathematics

Most parents[1] recognize the importance of being involved in their children's education, and they value their learning (Drummond & Stipek, 2004; Kliman, 2006). But, it is common that parents struggle helping their children learn and understand mathematics. Many parents feel inadequate helping their child(ren) with mathematics because they are not confident in their own mathematical ability, are unaware of the content, or do not have the teaching skills needed to help their child (Drummond & Stipek, 2004; Kliman, 2006; Lopez & Donovan, 2009; Pohan & Adams, 2007; Sheldon & Epstein, 2005). Drummond and Stipek (2004) argue parents who have low-income status are likely to help their child more with reading than with mathematics because they claim mathematics is not as important to everyday life, and they are not confident in their own mathematical ability. The changes in the way mathematics is taught may also contribute to this feeling of incompetency (Sheldon & Epstein, 2005). It has been found; however, when parents are taught how to work with their children, especially on mathematical concepts, they develop a better attitude toward school and the subject matter, which could influence students' attitudes toward mathematics (Peña, 2000). In fact, several qualitative research studies revealed a strong link between parents' and students' attitudes toward mathematics (Pedersen, Elmore, & Bleyer, 1986; Rowan-Kenyon et al., 2012; Sheldon & Epstein, 2005). Parents who have negative feelings toward mathematics, or who have openly acknowledged their own mathematics deficiencies tend to have children with similar attitudes (Usher, 2009). On the other hand, parents who encourage mathematics and mathematical thinking and have positive feelings toward the subject tend to have children who also enjoy it, making them more likely to succeed as well as pursue STEM-related careers in the future (Rowan-Kenyon et al., 2012).

Involving parents in their child's mathematics education may prevent the decline in students' attitudes toward mathematics (Sheldon & Epstein, 2005). Wilkins and Ma (2003) suggest involving parents and students in family math nights increases positive mathematics interactions between parents and their child(ren), and family math nights improves parents' attitudes and feeling of competence toward mathematics. Bringing together school and family communities into one may be beneficial to students' achievement and students' attitudes toward mathematics.

Students' Attitudes Toward Mathematics

According to Rowan-Kenyon et al. (2012), students are more likely to develop an interest in a subject if they feel competent or have high self-efficacy in that area, while they are likely to create an aversion to subject matter when they feel as if they will fail. Stodolsky et al. (1991) conducted a study with 60 fifth-grade students and found that mathematics was considered one of the hardest subjects. Contrary to other subjects, students' attitudes toward mathematics were based off their achievement rather than their interest. Similar to Usher's (2009) findings, students' negative attitudes were attributed to failure, feelings of difficulty, and frustration with the subject matter. Most students in Stodolsky, Salk, and Glaessner's (1991) study reported they did not believe they could learn mathematics on their own, but needed guidance from a teacher or parent, unlike social studies in which most students reported they could teach themselves. Researchers report students' attitude toward mathematics is a good indicator of their success in the subject, with positive attitudes leading toward higher achievement (Akin & Kurbanoglu, 2011; Tapia, 1996; Thorndike-Christ, 1991; Wilkins & Ma, 2003).

Students' attitudes toward mathematics generally decline when students enter middle school, but remain steady during their high school years (Aiken, 1970; Rice et al., 2012; Hannula, 2002; Stodolsky et al., 1991; Wilkins &

Ma, 2003). Although students' attitudes may decrease over time, Ma and Xu (2004) reported an increase in mean achievement across time. The researchers analyzed the Longitudinal Study for American Youth (LSAY) data for students in grades 7–12 and found that even though students' attitudes decreased, they still performed well. Therefore, it is possible that attitude does not affect achievement, or attitude and achievement may be inversely related.

Students who value and enjoy mathematics generally have a higher level of achievement (Gottfried, 1985). However, poor mathematics achievement has been linked to a decline in students' attitude toward mathematics (Ma & Xu, 2004). During elementary school, students are introduced to concepts slowly and repetitively, resulting in positive attitudes and achievement for most students. As the material gets more diverse and abstract, students' attitudes and achievement levels begin to decline (Hiebert et al., 2003). Students' prior attitude has an effect on later attitude, and students' prior achievement has an effect on later achievement, with the effect of prior achievement being stronger (Ma & Xu, 2004). Students' prior achievement predicted later attitude for grades 7–12. However, prior attitude did not predict later achievement (Ma & Xu, 2004). Therefore, achievement leads to a positive attitude, but a positive attitude does not necessarily lead to achievement. While this study argues a one-sided effect, several researchers conclude attitude and achievement influence one another in a cyclical fashion (e.g., Schiefele & Csikszentmihalyi, 1995). For example, Maple and Stage (1991) argue students' attitude toward mathematics, not achievement in mathematics, was a statistically significant predictor of selecting a mathematics major. On the other hand, achievement at the middle school level determines the curricular choices of students in higher-level mathematics (Singh, Granville, & Dika, 2002).

It is not only personal achievement that affects a student's mathematics attitude, but social support also has a great impact. According to Rice et al. (2012), middle school students are put into more ability grouped classes and have less support from their teachers who tend to think students cannot succeed, especially in lower-performing classes. This could account for part of the decline of students' self-efficacy, and in turn, their attitudes toward mathematics. Students receiving more positive support from teachers and parents tend to have more positive attitudes in mathematics (Maloney, Ramirez, Gunderson, Levin, & Beilock, 2015; Rice et al., 2012; Wilkins & Ma, 2003).

The decline in the middle school years could be due to students' negative perception of the social importance of mathematics as they are less likely to see a connection between what they are learning in mathematics and their everyday life (Gilroy, 2002; Rowan-Kenyon et al., 2012; Wilkins & Ma, 2003). However, it has been noted that middle school students' attitudes toward mathematics is highly related to their mathematics achievement (Aiken, 1970; Pedersen et al., 1986), and that attitudes toward the subject influences the number of mathematics courses they will take in high school and college (Gilroy, 2002). If students' attitudes toward mathematics can improve, it would in turn influence their achievement and interest in pursuing a STEM-related field (Gilroy, 2002; Rice et al., 2012).

While there have been several studies that regarded parents' attitudes toward mathematics as important and even some suggesting it has an effect on students' attitudes toward mathematics (Pedersen et al., 1986; Rowan-Kenyon et al., 2012; Sheldon & Epstein, 2005; Usher, 2009), little has been done quantitatively where parents participate directly. Student attitude scales have been developed and validated to measure student perceptions of parent attitudes, among other factors of student attitudes (Fennema & Sherman, 1976; Khine & Afari, 2014; Ngurah & Lynch, 2013; Tapia, 1996). Previous studies have largely used qualitative data collection and analysis to make a connection between parents' and students' attitudes toward mathematics or used quantitative data reported by their child(ren) to quantify their parents' attitude. These studies rely largely on *students' perception* [emphasis added] of parental support, expectation or attitudes toward mathematics (Asante, 2012; Mata, Monteiro, & Peixoto, 2012; Rice et al., 2012).

Maloney, Ramirez, Gunderson, Levine, and Beilock (2015) quantitatively studied the relationship between a parent's mathematics anxiety and what effect it had on their elementary (grades 1 and 2) student's achievement. This is the only known quantitative study that directly surveyed parent's mathematics anxiety or attitudes. In order to continue to investigate parents' attitudes toward mathematics and make stronger linkages regarding parents' influence on students' attitudes toward mathematics, there is a need for quantitative connections as well.

Methods

This project utilized a quantitative survey design in order to answer the following research questions: What are parents' and students' attitudes toward mathematics?

How do parents' attitudes influence their child(ren)'s attitudes toward mathematics?

We were interested in gaining a better indication of parents' attitudes toward mathematics and what kind of influence, if any, their attitudes had on their child(ren)'s attitudes.

Participants and Context

Convenience sampling was utilized to collect data from 468 adults and 770 students for seven years (2008–2015) at Family Math Night (FMN) events at multiple area elementary (grades K–5) and middle (grades 6–8) schools in a large urban school district in the upper south central region of the United States. A Family Math Night (FMN) is an event where students, their families, and the community come together for a night to have fun exploring content, activities, and games that support mathematical learning. FMNs are open to all families of students at the school site as well as the surrounding community. The school takes exhaustive recruitment measures to boost participation of families, including informational flyers and phone calls prior to the event, and transportation for families in need the evening of the event. Parents are asked to RSVP in order for the school to estimate the amount of food needed for the event. The phone calls are made to families who do not turn in RSVPs and reminder phone calls are made to families of underrepresented populations, particularly students of color, low socioeconomic status, and low-achieving students. While the schools encourage all families to attend, it is acknowledged families who do choose to attend may have a positive bias toward mathematics.

Data/Instrumentation

The surveys used for the current study were adapted from the Attitudes Toward Mathematics Inventory (ATMI; Tapia, 1996). ATMI was first administered to students at a private high school, and four-factors (self-confidence, value, enjoyment, motivation) were identified using exploratory factor analysis (EFA) techniques. Confirmatory factor analyses (CFA) have been performed in subsequent studies (Afari, 2013; Khine & Afari, 2014; Ngurah & Lynch, 2013), with results supporting instrument validation in different settings, including the setting of interest in the current study—middle grade students. Tapia and Marsh (2002) found the same four-factor model from the original validation (Tapia, 1996) held for the college students enrolled in mathematics courses. ATMI has also been applied to the middle school grades (Ke, 2008; Tapia & Marsh, 2000). Other efforts to develop shorter surveys using ATMI have also been done (Lim & Chapman, 2013).

The items adapted for the Parent Attitudes Toward Mathematics (PATM) and Brief Student Attitudes Toward Mathematics (BSATM) from ATMI were considered as a global measure for attitudes toward mathematics for this study, represented by a composite score used throughout the analysis. The additional factors were intentionally not considered because a single variable was determined to be reasonable as an overall measure of attitude.

Parent survey. The Parent Attitudes Toward Mathematics (PATM) survey is a 24-item, 5-point Likert scale survey (strongly disagree → strongly agree; neutral category) intended to measure a single construct of mathematics attitude. Example statements from the survey include:

- I do not like people to think I am smart in math.
- During math class, I was interested.
- I use math in some way every day.
- I feel confident when I help my child with math.
- It is okay if my child gets below a C in math.

The survey took parents approximately 5–8 minutes to complete. The Flesch Reading Ease was 96.3 and the Flesch-Kincaid Grade Level was 1.6 indicating all English-speaking adults should be able to understand the statements in the survey. Due to the nature of the events and to the limited amount of time available for participants to answer the survey, demographic information was not collected.

The PATM was first assessed for reliability using Cronbach's alpha for the instrument overall, $\alpha = .963$, indicating a very high reliability. Principal components analysis (PCA) was conducted on the PATM survey to assess for dimensionality and data reduction, thus supporting construct validity of the instrument. The first component explained 55.621% of the total variance. While three factors were extracted, PCA results suggested a single factor is reasonable. The eigenvalues corresponding to each of the three factors extracted were 13.349, 2.326, and 1.095, respectively. As the ratio of the first eigenvalue to the second eigenvalue is larger than three (Embretson & Reise, 2000) and, by more restrictive, earlier recommendations exceeds four (Lord, 1980), the use of a single factor is supported. The loadings garnered further support for a single measure of parents' attitude being represented by the instrument. The loadings for all of the items on the first component were salient (>0.3; Klein, 1994/2000). Where items loaded saliently on a second factor, the loading was stronger on the first component.

Student survey. While there are several attitudes toward mathematics surveys available (Chamberlin, 2010), the researchers needed an instrument that could be taken by elementary and middle school students in 3–5 minutes. Therefore, the research team administered the Brief Student Attitudes Toward Mathematics (BSATM) survey. The BSATM is a 6-item, 4 point Likert scale survey (strongly disagree → strongly agree; no neutral category) that

measures students' attitude toward mathematics. Statements from the survey included:

- I like math.
- Math is boring.
- I do not like people to think I am smart in math.

The Flesch Reading Ease of the BSATM was 100 and the Flesch-Kincaid Grade Level was 0.5 indicating all English-speaking school children should be able to understand the statements in the survey. Due to the nature of the Family Math Night and to the limited amount of time available for participants to answer the survey, demographic information was not collected.

The BSATM survey was first assessed for reliability using Cronbach's alpha, $\alpha = .86$, indicating a high reliability (Nunnally, 1978). The BSATM was then assessed for dimensionality and data reduction to ensure the validity of the instrument. A principal components analysis of residual explained 60.475% of the total variance in the measure, which fit the expected results.

Data collection. Both surveys were administered during FMNs (described above) at a booth for the students and a booth for the parents. The survey was administered on paper the first two years. Thereafter, the survey was given online using first a secure Moodle platform, and then migrating to Google Forms. Paper copies continued to be used at schools where internet access was unavailable. The survey administration was closely monitored for each event to minimize any outside people accessing the survey. There was only one instance of a nonfamily math night participant taking the survey and it was removed.

Efforts were made to get parents to participate. For example, incentives were provided for both the parents and the students to take the survey. The parents were entered into a drawing for prizes geared toward parents including, coffee mugs, gift cards to restaurants, massages, and so forth. The students received a stamp on their booth sheet (they had opportunities to collect stamps from all the booths at the event) and they turned in their stamped booth sheet at the end of the event to be entered into a drawing for educational door prizes. Food and water was provided for parents and students at the events.

Data Analysis

The project utilized a quantitative survey design to answer the following research questions: What are parents' and students' attitudes toward mathematics? How do parents' attitudes influence their child(ren)'s attitudes toward mathematics? Survey data analyses were carried out with SPSS 21.0, a software package used for organizing data, conducting statistical analyses, and generating tables and graphs that summarize data. All cases were originally included in the data set. No cases were removed. Missing scores of the cases were imputed (mode for a given item) in line with Hox's (2010) discussion and the assumption that parents and students who took each survey were representative of the population of interest, respectively.

The data analyses involved several steps. First, descriptive statistics were applied to analyze overall item response percentages and note any possible trends in responses. Next, we used one-tailed Pearson correlations to examine the relationships between students' attitudes toward mathematics and parents' attitudes toward mathematics. Lastly, a single predictor regression model was created to examine the extent to which the parents' attitude toward mathematics predicted their child(ren)'s attitudes toward mathematics.

Results

To examine the influence of parents' attitude toward mathematics on students' attitudes toward mathematics, cases were matched by names given on the survey—parents provided the student(s)' name(s), and students provided their parents' names. It was optional to provide names on each of the surveys. There were eight cases in which two parents from the same family responded to the survey and had only one student's response. The students' responses for the eight cases were replicated and matched with the other parent's responses, creating 146 matched cases.

Parents' Attitudes Toward Mathematics Survey

Overall, parents displayed favorable attitudes toward mathematics. All except one item yielded an average of at least three on a five-point scale. In the context of the scale responses, this means parents either did not know, agreed, or strongly agreed. For 5 of the 24 items, the average was at least four, indicating an average response of agree. The mean and standard deviation for all parents' attitudes are presented in Table 1.

The skewness (–.667) and kurtosis (.061) were within the normal distribution range of −1.0 to 1.0 (Huck, 2012) for the distribution of mean parents' attitude score for parents who we matched data with their child(ren) (Figure 1).

Table 1
Descriptive Statistics of Parent and Student Attitudes Toward Mathematics (n = 146)

	Mean	Standard Deviation
Student Attitude	3.244	0.535
Parent Attitude	3.989	0.684

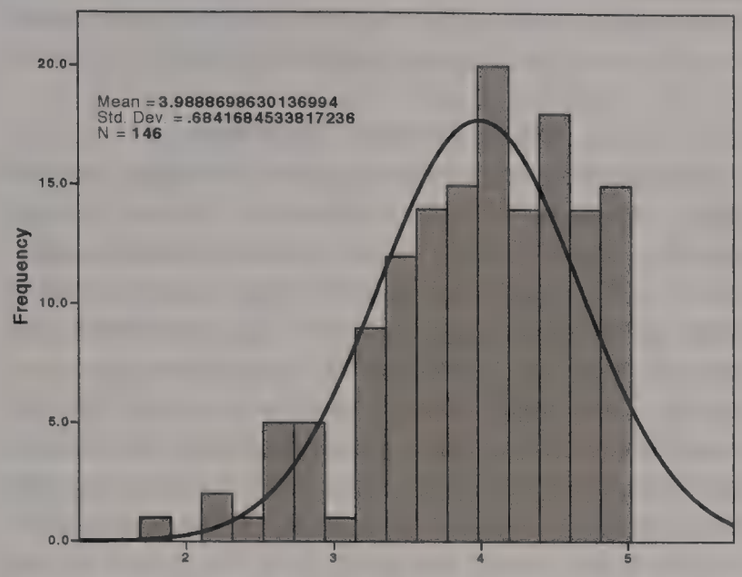

Figure 1. Histogram of Parent Attitudes ($n = 146$).

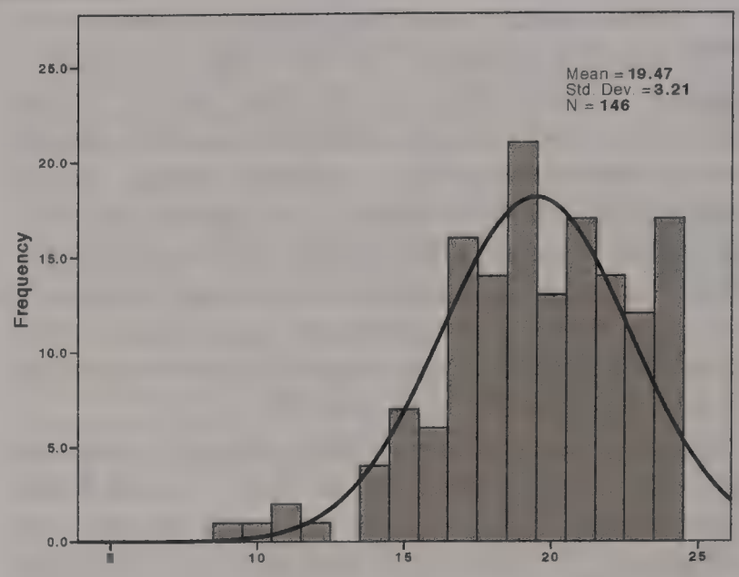

Figure 2. Histogram of Student Math Attitudes Scale ($n = 146$).

Brief Student Attitudes Toward Mathematics Survey

The overall mean of the students' attitudes was 3.244 and the mode was 3.17 ($n = 146$). Even though the distribution was slightly negatively skewed (skewness = –.641; kurtosis = .389), the skewness and kurtosis were within the normal distribution (Figure 2).

Relationship Between Parent and Student Attitudes Toward Mathematics

To examine the relationship between parents' attitudes toward mathematics and their child(ren)'s attitude toward mathematics, we applied correlation and regression techniques to the 146 matched cases. Table 2 displays Pearson correlation results of the parent survey and the student survey. The parents' survey scales showed statistically significant positive correlations with the student's attitude survey. The parents' attitude toward mathematics was positively correlated to students' attitudes toward mathematics ($r = .237$, $p = 0.002$).

We ran a one predictor regression using the parents' attitude as the independent variable and student's attitude as the dependent variable. Parents' and students' attitude scores were calculated by computing the mean score of all items for parents and students. We obtained the following model: $\hat{y}=.185x+2.506$, where $\hat{y}$ is the predicted mean student attitude score, and x is mean parent attitude score. For each additional point toward parents' attitude toward math, we can expect students' attitude to increase by .185 points on average (approximately 1/5 of a point). Although the range of parents' attitude scores is 1–5, we can loosely interpret the intercept, where a parent's attitude score of 0 would indicate the absence of a parent's attitude score. In this scenario, we can expect a student's attitude to be 2.506, which would be a neutral, neither favorable nor unfavorable attitude toward mathematics.

The results from the single predictor model were statistically significant [$R^2 = .056$; $F = 8.547$; $p = .004$], where 5.6% of the variation in students' attitude can be explained by the variation in parents' attitude. Although small, the variation is not unexpected. We hypothesize that by looking at subscales for parents' attitude and making changes to our instrument, we will better understand details of how parent attitudes toward mathematics predicts student attitudes toward mathematics. Ultimately although, we do not expect the effect size to increase drastically considering the numerous other factors that influence student attitudes toward math (e.g., self-efficacy, anxiety, social supports, experiences at school and home). For example, Mata et al. (2012) performed hierarchical analysis using structural equation modeling and found student background alone (gender, grade achievement) yielded an $R^2 = .089$, but when combined with motivation, and then when background and motivation were combined with support (teacher and peers), the effect size increased to $R^2 = .402$ and $R^2 = .643$, respectively.

Table 2
Pearson Correlations between Parent Survey and Student Survey (n = 146)

Scale	1	2
1. Student math attitude	1	
2. Parent math attitude	.237*	1

*Correlation is statistically significant at the $p < 0.01$ level (1-tailed).

Discussion, Conclusions, and Implications

"A student's attitude is the most important factor in success" (Tapia, 1996, p. 12). The purpose of this quantitative study was to investigate parents' attitudes toward mathematics, their students' attitude toward mathematics, and the influence of the parents' attitude on the student's attitude within a single environment, Family Math Nights. While qualitative connections between the two have been made previously (e.g., Usher, 2009), quantitative studies to date investigating this relationship have been minimal (Maloney et al., 2015).

Overall, parents' displayed highly favorable responses. However, parents who make an effort to attend Family Math Nights could have more positive attitudes toward mathematics. Or, they could participate in Family Math Nights because they see the value for their child(ren). We will not be able to speak to motivation to attend Family Math Nights without further understanding the attitudes themselves. The use of subscales in subsequent data collection, we hypothesize, will deepen understanding of the influence of interest. We have begun exploring those subscales, using the six subscales of the ATMI, as the starting point.

Although the effect size of parent attitude, measured using the PATM, is small, these results are still encouraging and confirm previous studies indicating a connection between parent and student attitudes toward mathematics (Maloney et al., 2015; Pedersen et al., 1986; Rowan-Kenyon et al., 2012; Sheldon & Epstein, 2005; Usher, 2009). The lower positive correlations and unaccounted for variance could be due to the smaller sample size ($n = 146$ matched cases).

There are a number of possible limitations to this study related to sampling procedures and the population of interest. Potential biases that arise from convenience sampling strategies could include repeated cases across survey administrations. While this is possible for individual parent and student data, the matched parent and student data ($n = 146$) were unique in this study. The FMN itself could confound results related to effect size of parent attitudes in predicting student attitudes. For instance, readers may think about how participation in FMN could impact parents' responses. While this concern may be plausible for items such as "I like math" where participation in math activities during FMN could result in some change in response; other items such as "I do not feel comfortable helping my child(ren) with math homework" (item 25), "I use math in some way every day" (item 17) and "taking math was a waste of time" (item 7) were designed to account for parents' attitude beyond a single instance. However, small changes in responses for some items would not reflect a larger change in composite scores.

Future Research Directions

The purpose of this research was to determine whether parent attitudes toward mathematics impact student attitudes toward mathematics among middle grades students. While additional validity assessment is needed in order to observe the capabilities of the instruments, this research provided a preliminary investigation into how quantitative methods could be used to understand attitudes toward mathematics. The methods applied in this research could be applied to future research in coordination with psychometric techniques to provide further evidence of validation that would strengthen how the results of this research are interpreted and applied by educational researchers. Subsequent research should focus on how the subscales can be used to identify unique contribution of different factors in explaining the impact of parent attitude on student attitude. Additional data collection should continue, especially in collecting matched cases for parent and student responses.

Conclusions and Implications

Many students come to school with a negative attitude toward mathematics. This is compounded as they go through the grade levels into more challenging mathematics (Rowan-Kenyon et al., 2012). Many of these attitudes stem from their parents (Maloney et al., 2015) and elementary teachers who themselves are afraid of mathematics and/or have a negative attitude toward it. As students' progress through the grade levels, they may come across influential figures who dislike mathematics, increasing students' negativity toward mathematics. Most of the time, the negative attitude is simply because the students have told themselves they cannot do mathematics; they are never going to use it anyways; and so forth. School-based factors are compounded when they are reinforced at home, such as parents' negative attitudes toward mathematics. With the introduction and implemented use of standards-based curricula, many parents have become more resistant to mathematics. Much of this is because they do not understand how and why mathematics is being taught currently.

It is important to open communication barriers between parents and teachers about mathematical content, which can then help students succeed in mathematics, and in turn, support the creation of positive interactions that foster positive attitudes (Drummond & Stipek, 2004; Lopez & Donovan, 2009; Sheldon & Epstein, 2005). The perceived support from parents and teachers has a large effect on

career-related outcomes for middle school students, especially in mathematics and the sciences (Rowan-Kenyon et al., 2012). We know early interest in STEM subjects, especially among middle school students, results in an increase desire to persist and persevere in mathematical tasks (Rowan-Kenyon et al., 2012). It is important to open communication between parents and teachers and allow parents to learn specific strategies/activities to help their child with mathematics at home (Bofferding et al., 2016; Drummond & Stipek, 2004; Jacobbe et al., 2012). By helping foster favorable parental attitudes toward mathematics, parents can become a more positive influence on their child(ren)'s mathematical attitude, which can increase students' achievement and interest in mathematics.

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Authors' Notes

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[1]For consistency, child(ren) and parents will be used throughout the article. However, the researchers recognize that there are situations where students have guardians different from their parents.

Corrigendum

This corrigendum seeks to clarify that the items included in the appendix of [1] are modifications of existing tools that were utilized in constructing the survey tool (MTBELL). Particularly, items 9, 40, 13, and 37 present modifications of items 22, 23, 31, and 32 of Fernandes and McLeman's Mathematics Education of English Learners Scale (MEELS) survey instrument. Though the tool is cited in the text of the paper, the authors recognize that they should have provided full citations in the appendix so that readers will have the full reference when reviewing the items. Below are full citations for papers related to those items.

Fernandes, A., & McLeman, L. (2012, November). *Developing the mathematics education of English Learners scale (MEELS)*. Paper presented at the North American Chapter of the International Group for the Psychology of Mathematics Education, Radisson Hotel, Kalamazoo.

McLeman, L., Fernandes, A., & McNulty, M. (2012). Regarding the mathematics education of English learners: Clustering the conceptions of prospective teachers from urban universities. *Journal of Urban Mathematics Education, 5*, 112–132.

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We apologize for this error.

1. Gann, L., Bonner, E. P., & Moseley, C. (2016), Development and Validation of the Mathematics Teachers' Beliefs About English Language Learners Survey (MTBELL). *School Science and Mathematics, 116*: 83–94. doi: 10.1111/ssm.12157

PROBLEMS section

Ted Eisenberg, *Section Editor*

This section of the Journal offers readers an opportunity to exchange interesting mathematical problems and solutions. Please send them to Ted Eisenberg, Department of Mathematics, Ben-Gurion University, Beer-Sheva, Israel or fax to: 972–86-477–648. Questions concerning proposals and/or solutions can be sent e-mail to eisenbt@013.net. Solutions to previously stated problems can be seen at http://www.ssma.org/publications.

Solutions to the problems stated in this issue should be posted before September 15, 2017

▪ **5451**: *Proposed by Kenneth Korbin, New York, NY*
Given triangle ABC with sides $a=8, b=19$ and $c=22$. The triangle has an interior point P where $\overline{AP}$, $\overline{BP}$, and $\overline{CP}$ each have positive integer length. Find $\overline{AP}$ and $\overline{BP}$, if $\overline{CP}=4$.

▪ **5452**: *Proposed by Roger Izard, Dallas, TX*
Let point O be the orthocenter of a given triangle ABC. In triangle ABC let the altitude from B intersect line segment AC at E, and the altitude from C intersect line segment AB at D. If AC and AB are unequal, derive a formula that gives the square of BC in terms of AC, AB, EO, and OD.

▪ **5453**: *Proposed by D.M. Bătinetu-Giurgiu, "Matei Basarab" National College, Bucharest, Romania and Neculai Stanciu, "George Emil Palade" School, Buzău, Romania*
If $a, b, c \in (0,1)$ or $a, b, c \in (1,\infty)$ and m, n are positive real numbers, then prove that

$$\frac{\log_a b+\log_b c}{m+n\log_a c}+\frac{\log_b c+\log_c a}{m+n\log_b a}+\frac{\log_c a+\log_a b}{m+n\log_c b}\geq\frac{6}{m+n}$$

▪ **5454**: *Proposed by Arkady Alt, San Jose, CA*
Prove that for integers k and l and for any $\alpha, \beta \in \left(0, \frac{\pi}{2}\right)$ the following inequality holds:

$$k^2\tan\alpha+l^2\tan\beta\geq\frac{2kl}{\sin(\alpha+\beta)}-(k^2+l^2)\cot(\alpha+\beta).$$

▪ **5455**: *Proposed by José Luis Díaz-Barrero, Barcelona Tech, Barcelona, Spain*
Find all real solutions to the following system of equations:

$$\frac{1}{a}+\frac{1}{b}+\frac{1}{c}=\frac{1}{abc}$$

$$a+b+c=abc+\frac{8}{27}(a+b+c)^3$$

• **5456**: *Proposed by Ovidiu Furdui, Technical University of Cluj-Napoca, Cluj-Napoca, Romania*
Let k be a positive integer. Calculate

$$\lim_{x\to\infty} e^{-x}\sum_{n=k}^{\infty}(-1)^n\binom{n}{k}\left(e^x-1-x-\frac{x^2}{2!}-\cdots-\frac{x^n}{n!}\right).$$

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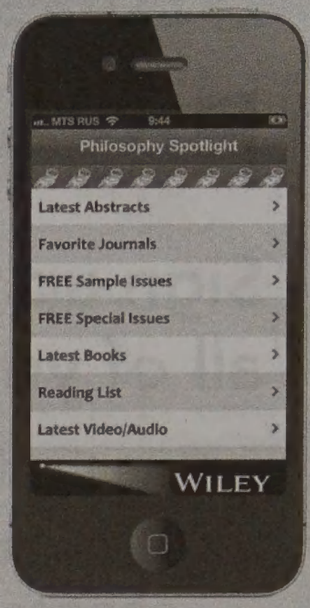

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